Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Dust prediction models

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Training Workshop on Sand and Dust Storms in West Asia, La Laguna, Tenerife, Spain, 21 May 2018

Questions will be welcome!

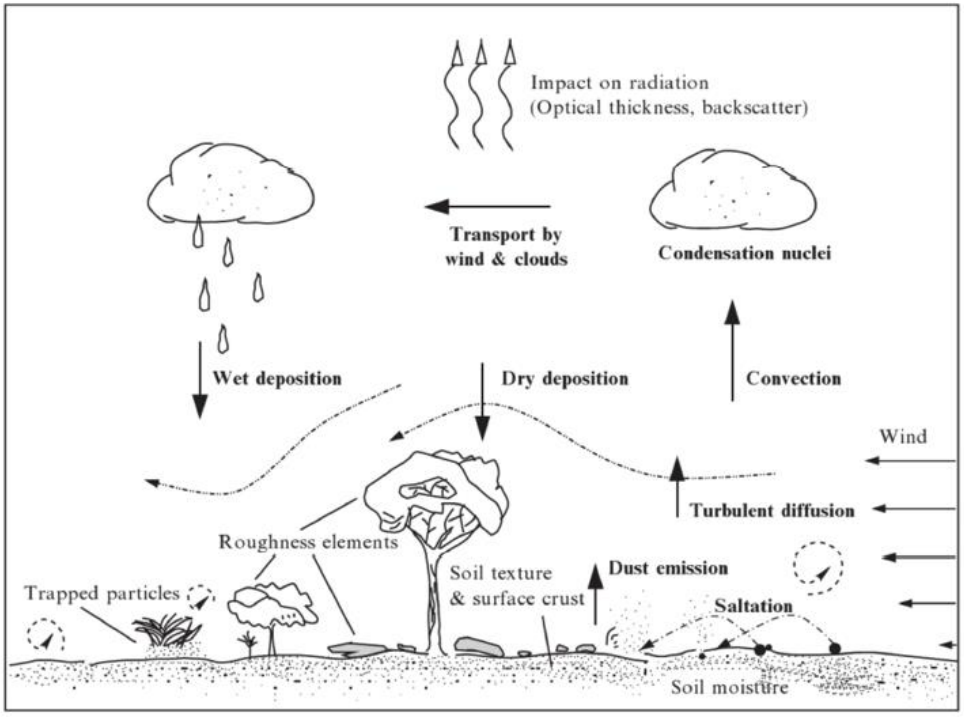
Introduction

What do we need to forecast dust storms?

1. Satellites, surface observations, NWP models and dust models.
2. Good knowledge of the dust climatology in the region.
3. Good knowledge of observation limitations.
4. Good knowledge of the dust model limitations.

Dust forecasting models

Dust models are a mathematical representation of atmospheric dust cycle.



Extracted from Shao (2008)

- ✓ *To complement dust-related observations, filling the temporal and spatial gaps of the measurements.*
- ✓ *To help us to understand the dust processes and their interaction with climate and ecosystems.*
- ✓ *To predict the impact of dust on surface level concentrations used as* ***SHORT-TERM FORECASTING TOOLS*** *(3-5 days ahead)*

Dust forecasting models

Dust forecasting models do **not** take account dust **resuspension**

Kathmandu, Nepal, March 2017

Outlook

1. **Dust cycle and associated processes**

   - *The atmospheric dust cycle*
   - *Dust global climatology*
   - *Types of dust storms and model forecasting skills*

2. **Dust forecasting models**

   - *Dust emission schemes and dust sources*
   - *Dust transport*
   - *Dust deposition and sedimentation*

3. **Modeling the dust cycle at BSC: From R&D to operational**

Dust cycle and associated processes

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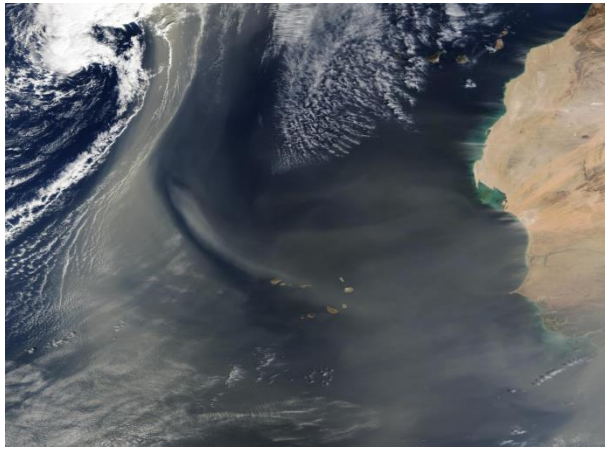
Dust cycle and associated processes

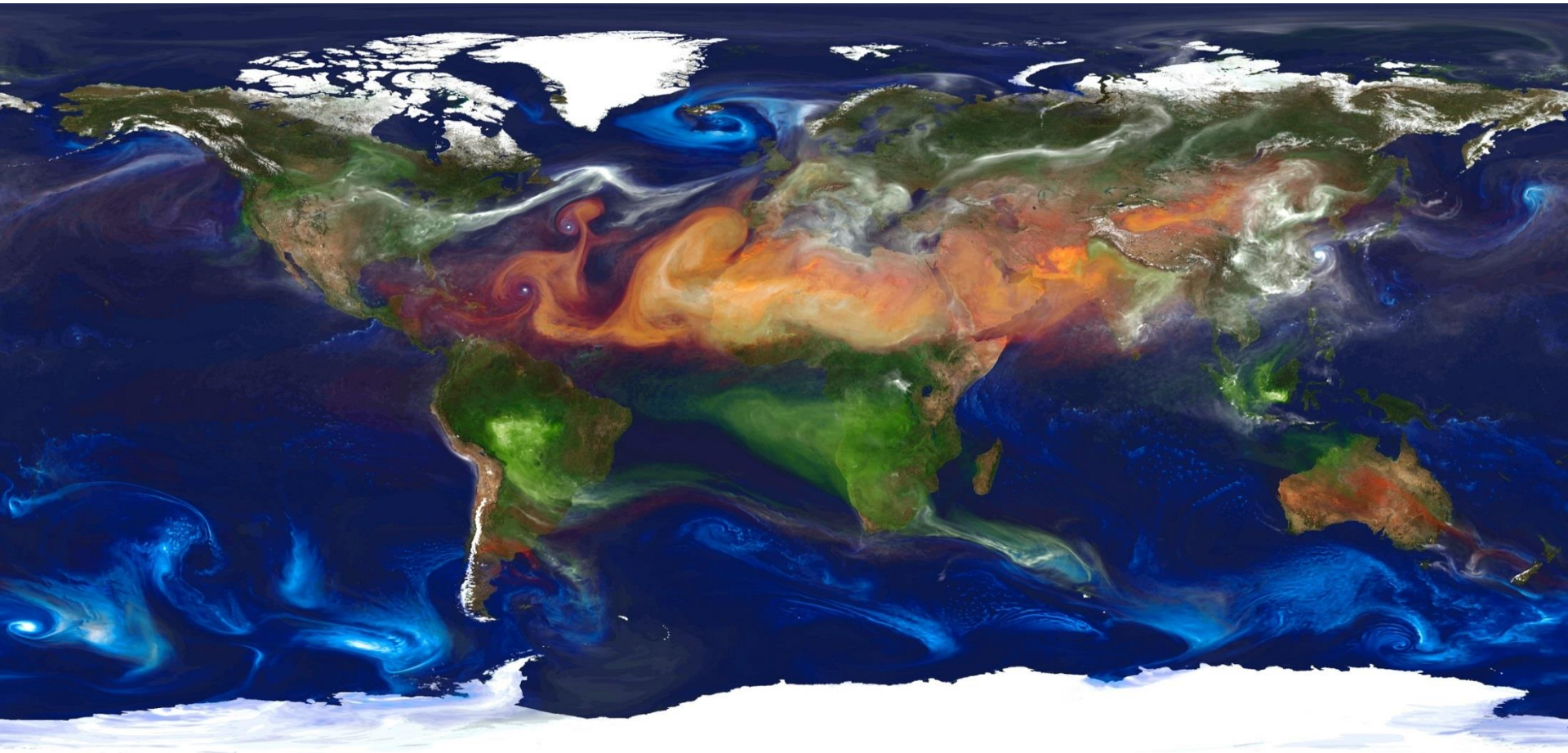
MODIS true colour composite image for March 2005 depicting a dust storm initiated at the Bodélé Depression (Chad Basin)



MODIS True color Western Africa – Altantic Ocean

Dust transport is a global phenomenon. However, **dust emission** is a threshold phenomenon, sporadic and spatially heterogeneous, that is locally controlled on small spatial and temporal scales.

Dust cycle and associated processes

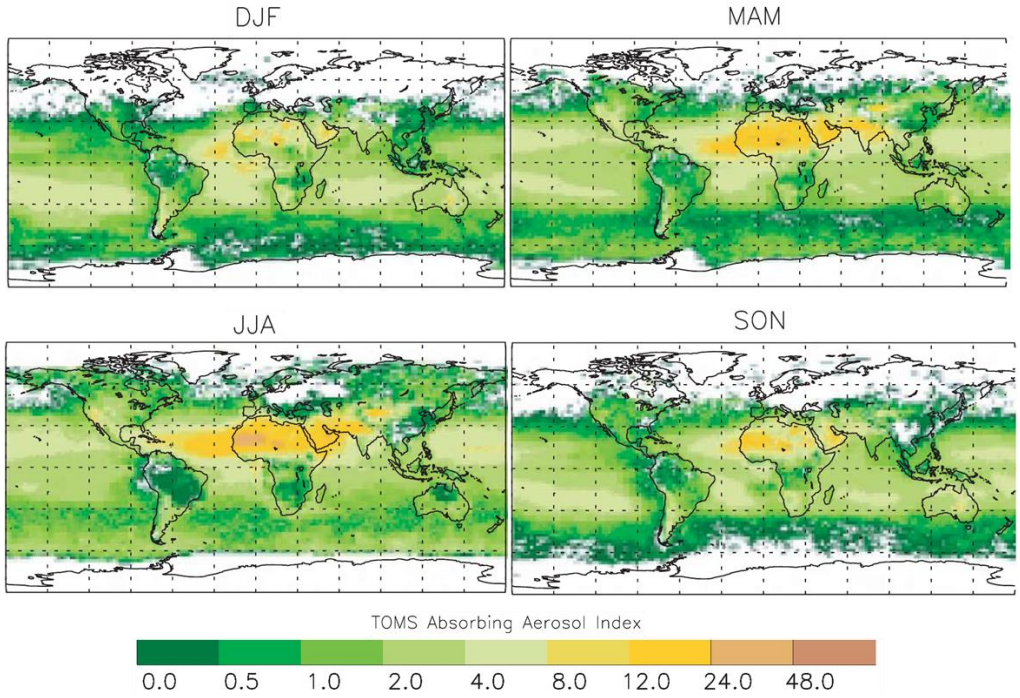


Organic Carbon + Elemental carbon
Dust
Sulfate
Sea salt

NASA | GEOS-5 Aerosols

Dust cycle and associated processes

Temporal changes in the dust distribution: SEASONAL and DECADAL CHANGES



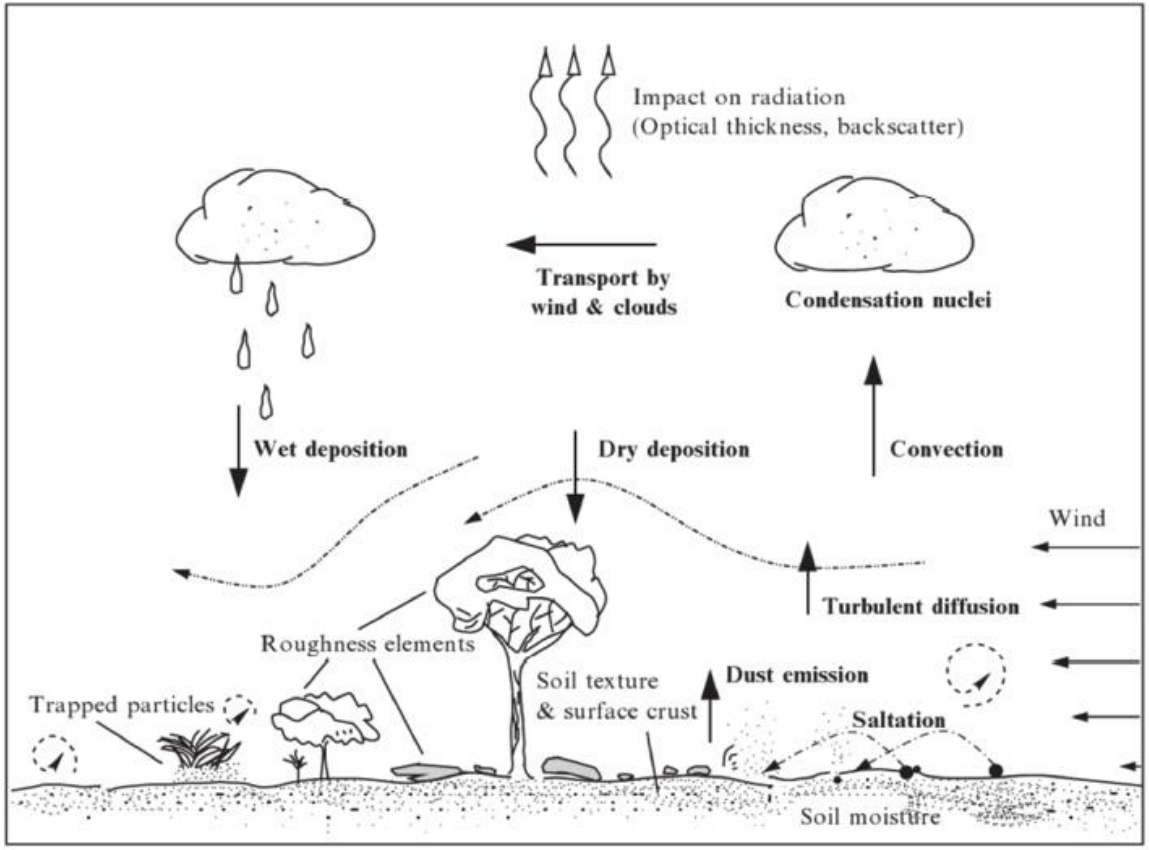
• Seasonal dust distribution changes well characterized. Follows seasonal changing weather regimes (mainly) and vegetation changes (in semi-arid areas)

• Interannual/decadal changes are controlled by climate and surface modification (land use, desertification). Decadal changes are not well captures by models

Figure extracted from Tegen al. (2002)

Dust cycle and associated processes

The atmospheric dust cycle and involves a variety of processes:



Extracted from Shao (2008)

- Dust emission from dry unvegetable surfaces (dust sources)
- Mid- and long-range transport
- Sedimentation, wet and dry deposition

Dust cycle and associated processes

Dust Impacts

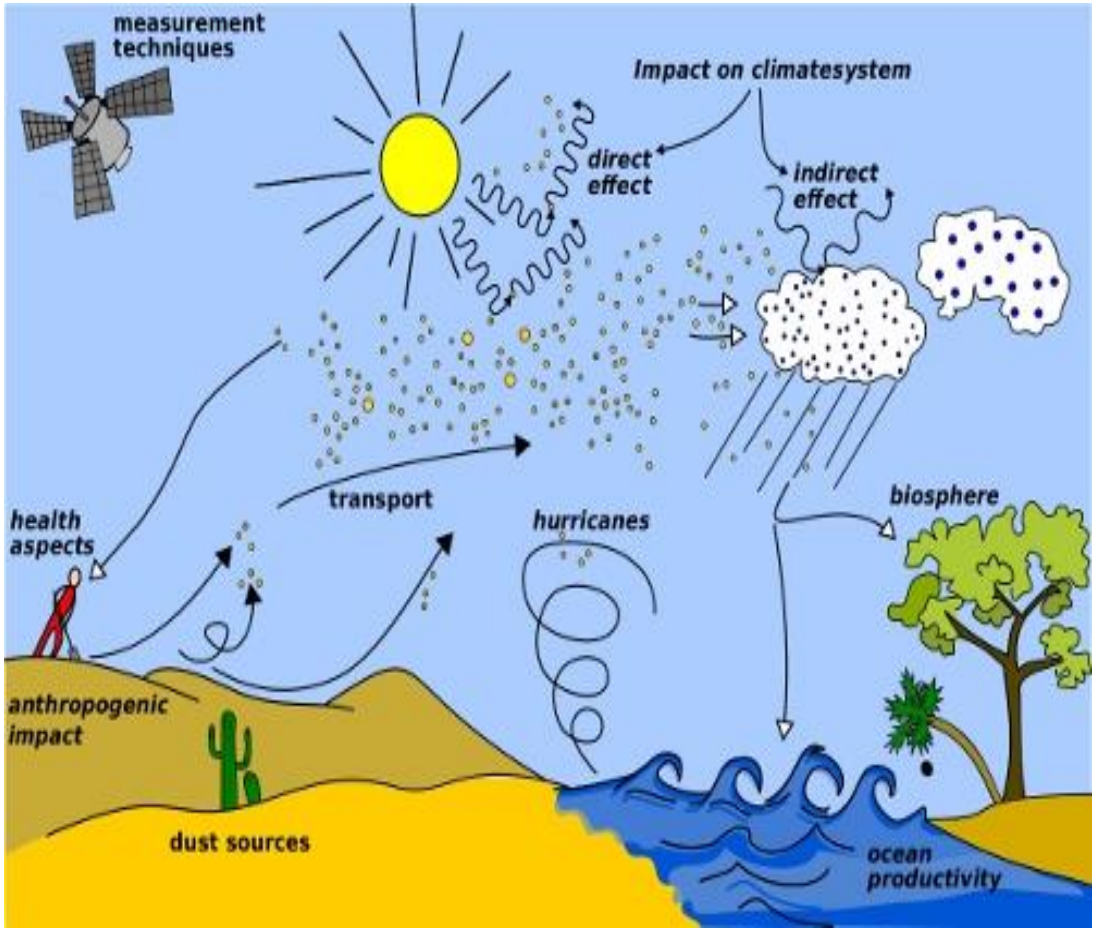


Image from WMO website (http://www.wmo.int/pages/prog/arep/wwrp/new/hurricanes.html)

Ecosystems, meteorology and climate

- *Marine productivity*
- *Coral mortality*
- *Hurricanes formation*

Air Quality and Human Health

- *Respiratory disease (asthma)*
- *Eye infections*
- *Meningitis in Africa*
- *Valley Fever in the Americas*

Aviation and Ground Transportation

- *Low visibility (i.e. air disasters)*

Agriculture and fishering

Energy and industry

Dust cycle and associated processes

Types of dust storms:

Synoptic dust storms (large scale weather systems)

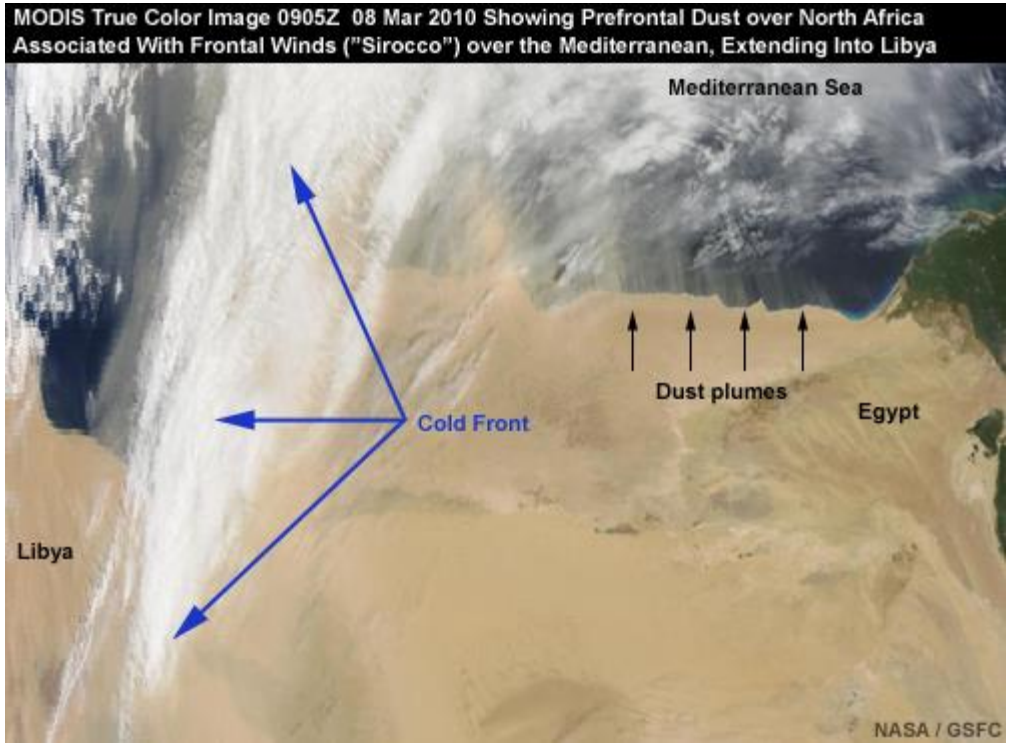
- Prefrontal winds
- Postprontal winds
- Large-scale Trade winds
- …

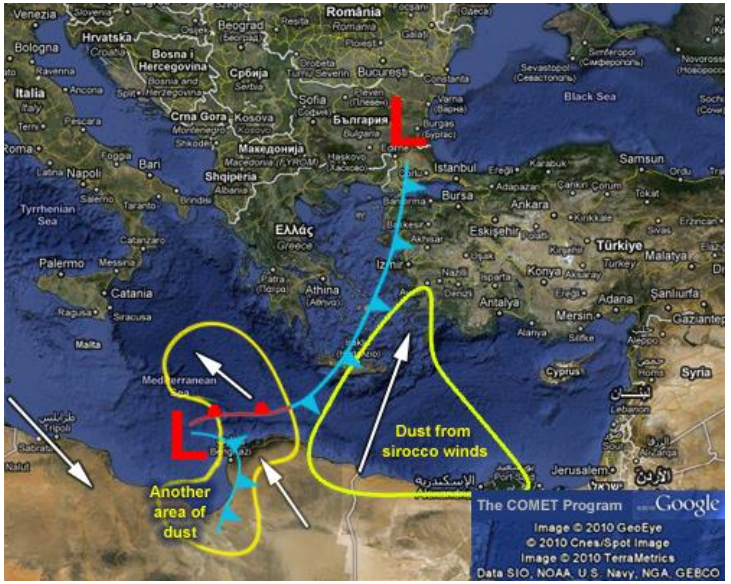
Mesoscale dust storms

- Downslope winds
- Gap flow
- Convection (dust devils and Haboobs)
- Inversion downburst storms
- …

Dust cycle and associated processes

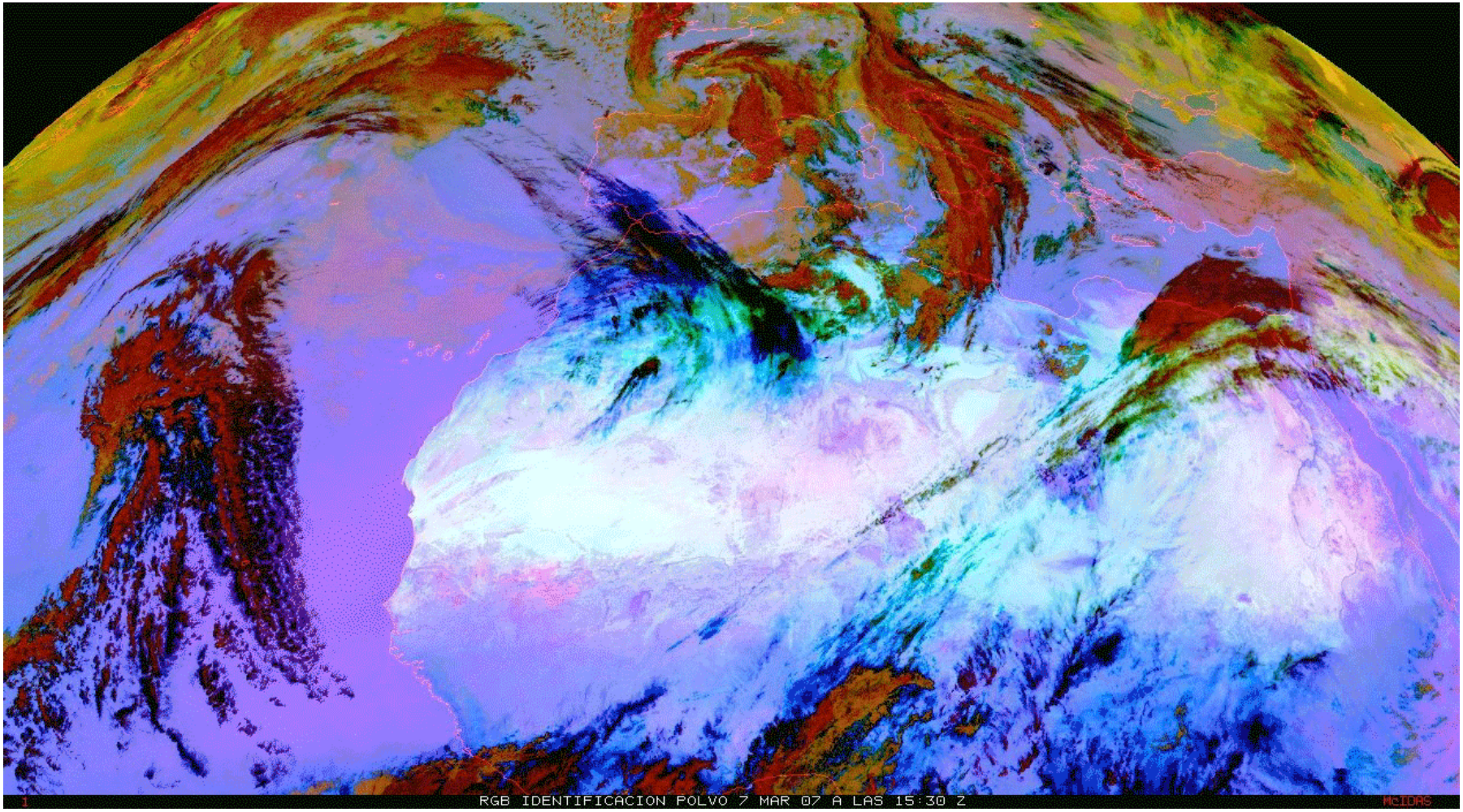
Synoptic dust storms: Pre-frontal





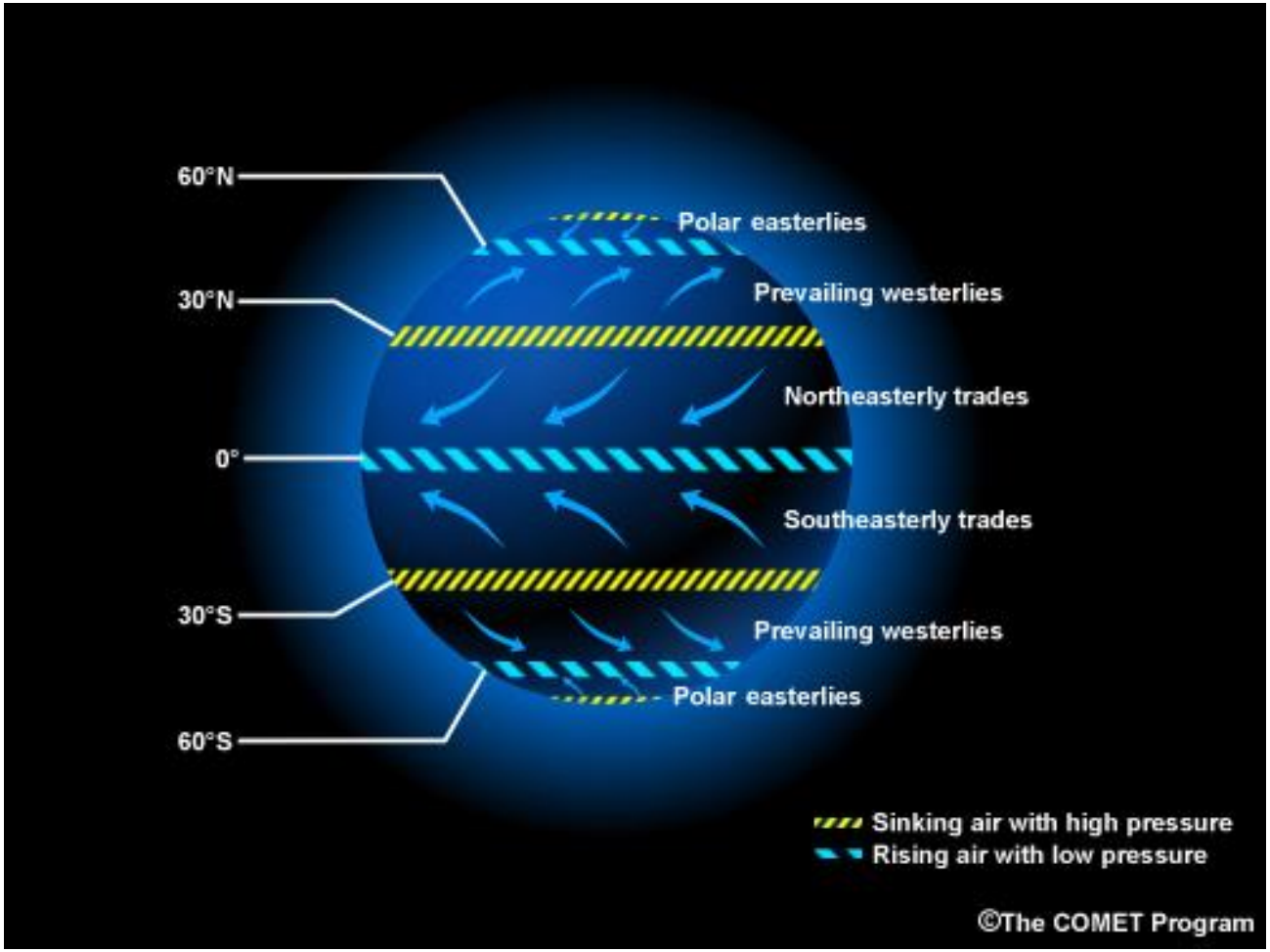
Dust cycle and associated processes

Synoptic dust storms: Post-frontal



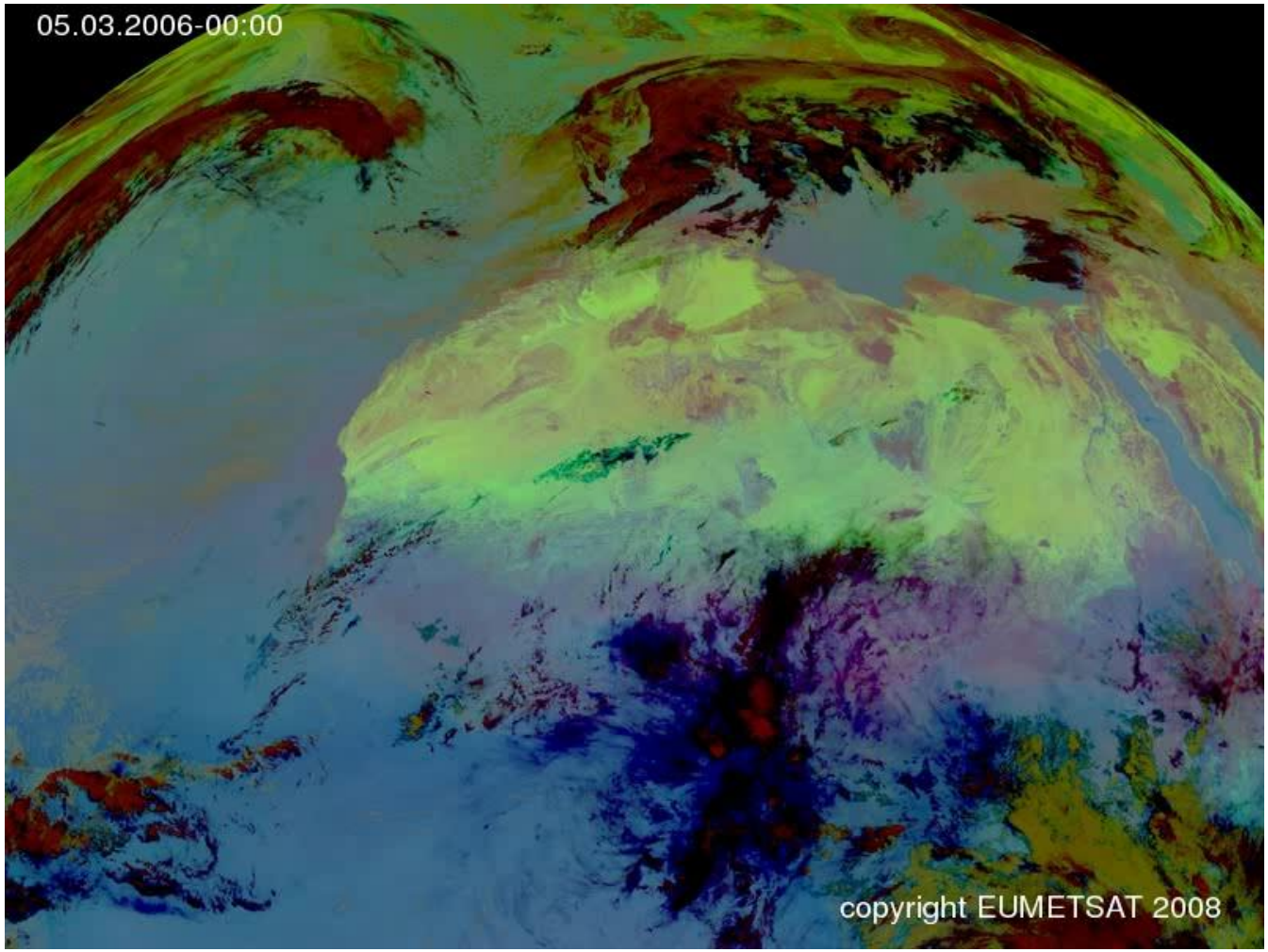
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



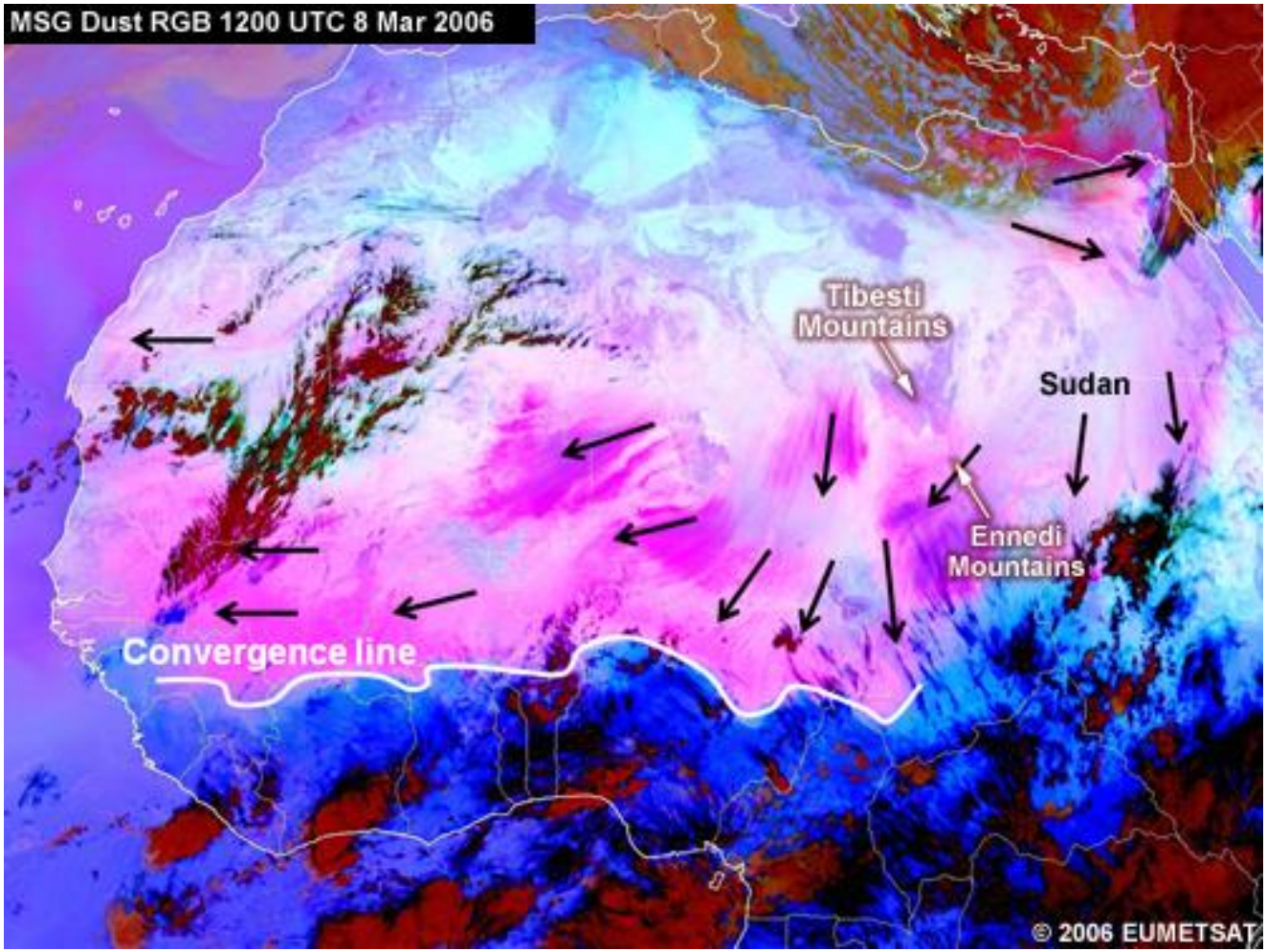
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



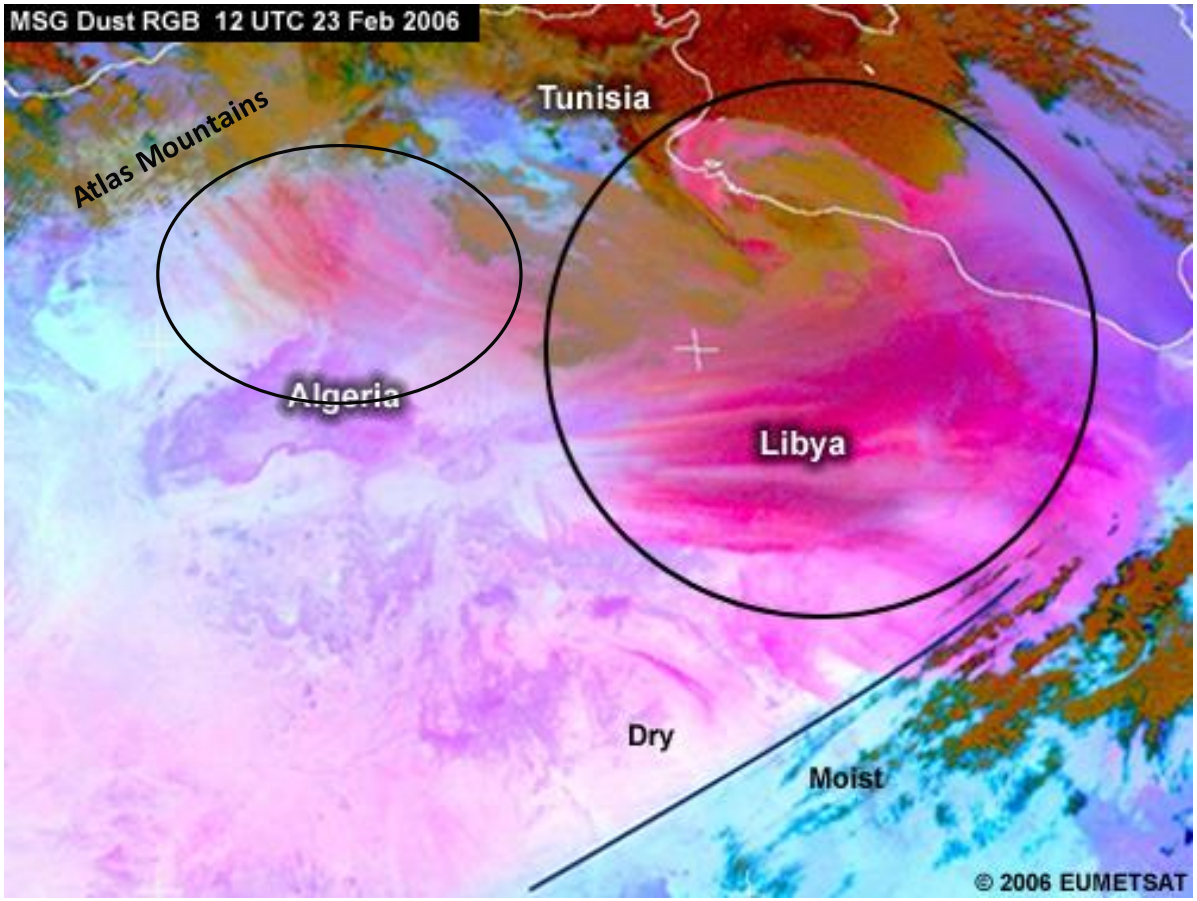
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



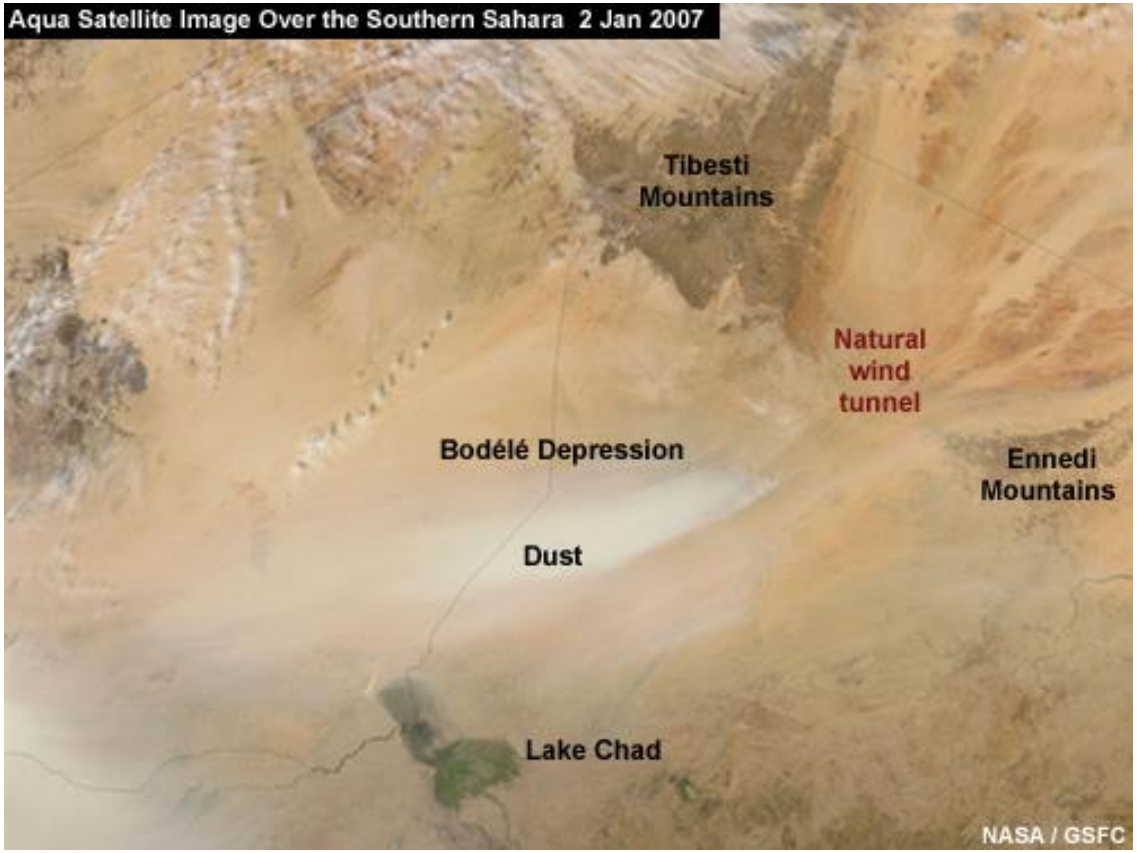
Dust cycle and associated processes

Mesoscale dust storms: Downslope winds



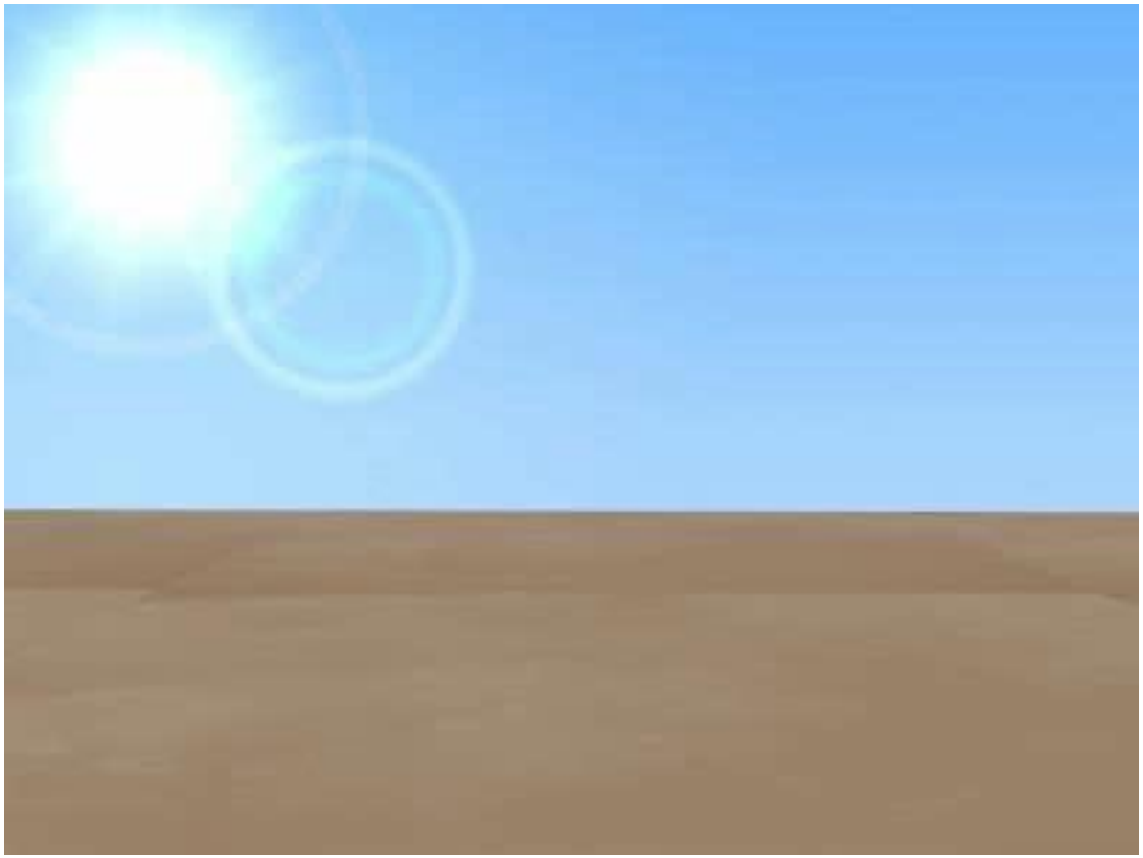
Dust cycle and associated processes

Mesoscale dust storms: Gap flow



Dust cycle and associated processes

Mesoscale dust storms: Dust devils (convection)



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

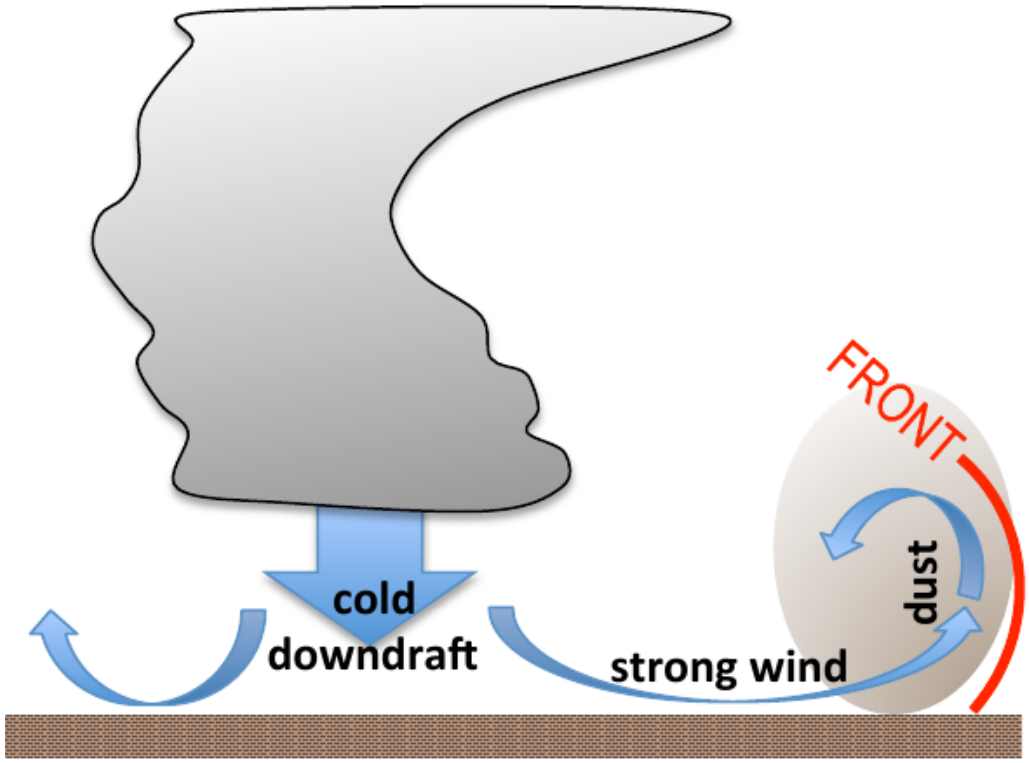
Mesoscale dust storms: Haboobs

Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

Mesoscale dust storms: Haboobs

Intensive cold downbursts from convective cells produced high velocity surface wind, creating cold front which was lifting, mixing and pushing dust

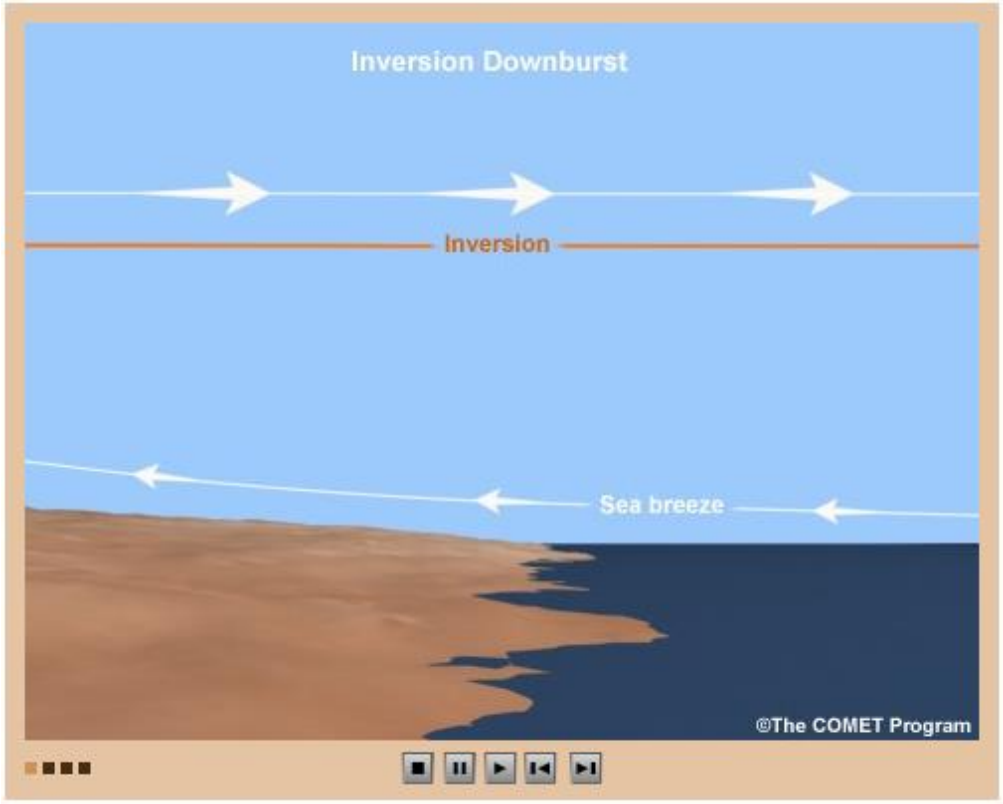


Expected: high wind speed, drop in temperature, rise in humidity, rise in pressure, reduction of visibility.

(Vukovic et al., in preparation)

Dust cycle and associated processes

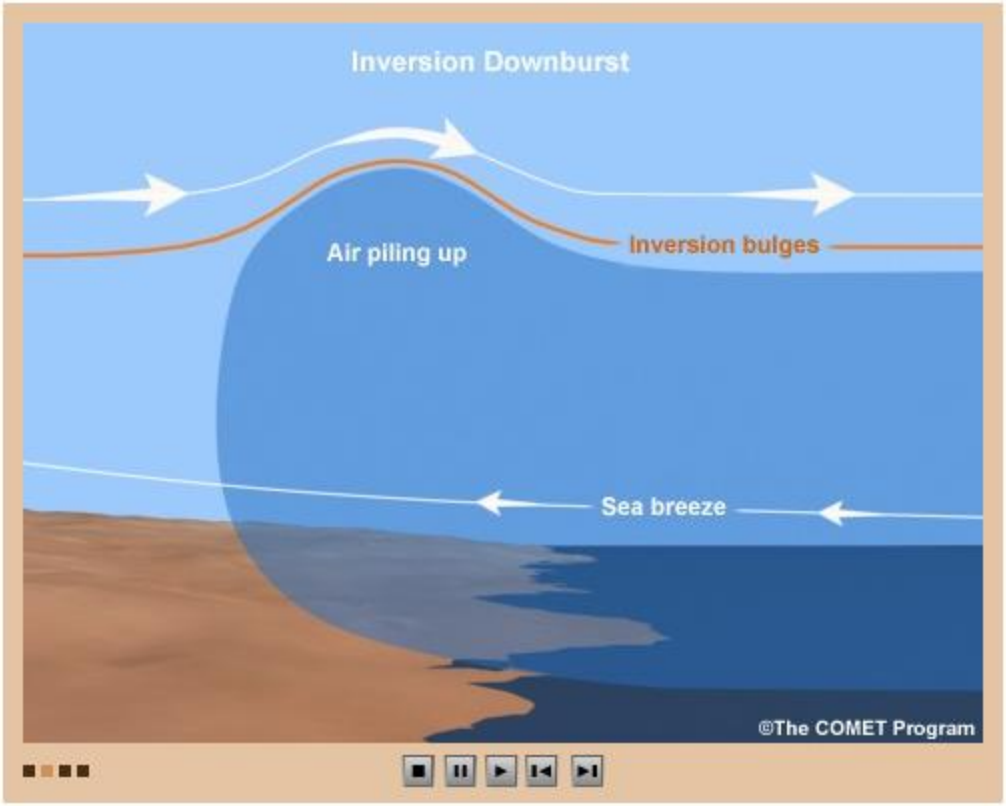
Mesoscale dust storms: Inversion downbursts



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

Mesoscale dust storms: Inversion downbursts



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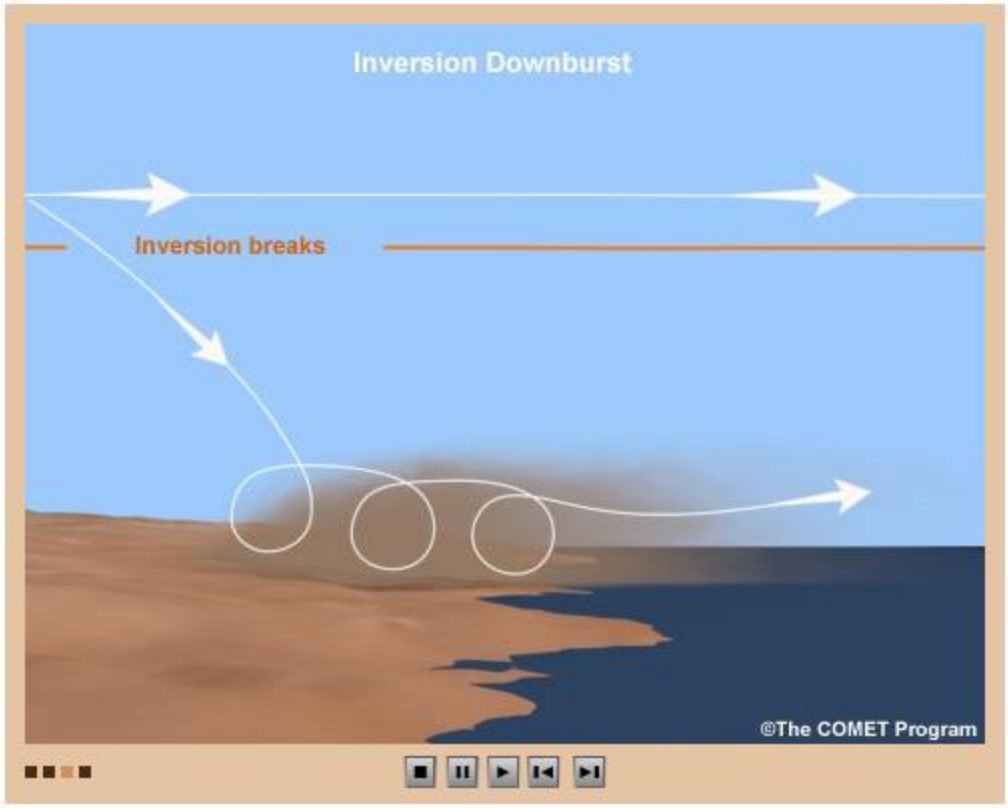
Dust cycle and associated processes

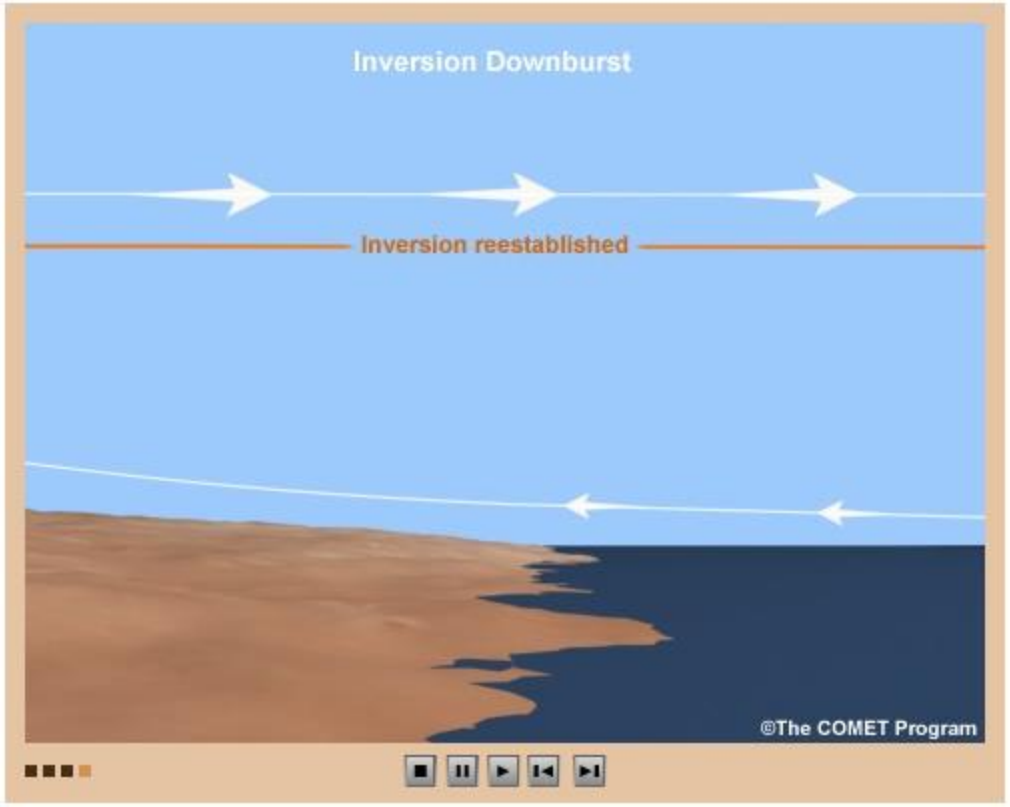
Mesoscale dust storms: Inversion downbursts



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

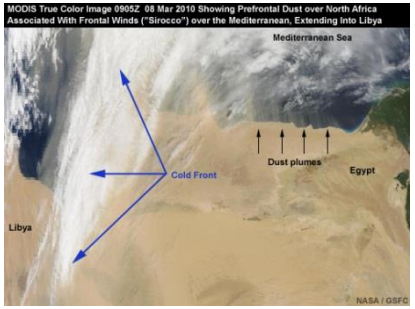
Mesoscale dust storms: Inversion downbursts



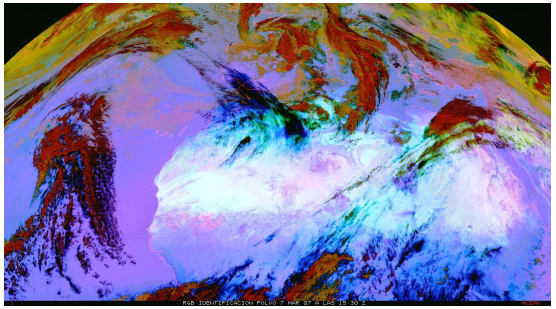
Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

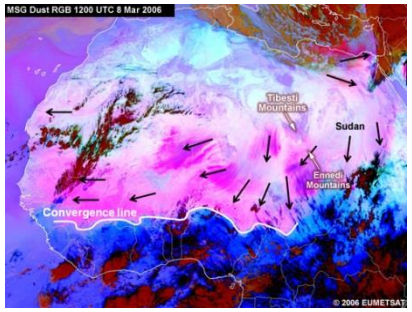
Synoptic dust storms (large scale weather systems) **Well captured by models.**



Pre-frontal winds

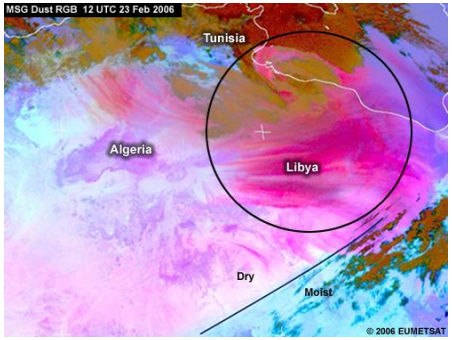


Post-frontal winds

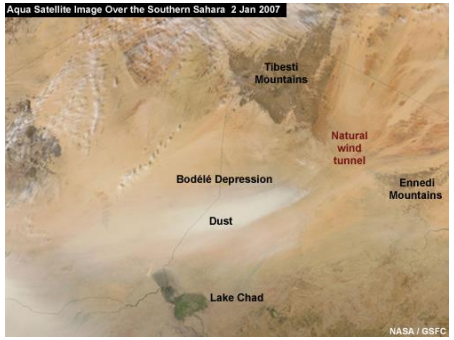


Large-scale trade winds

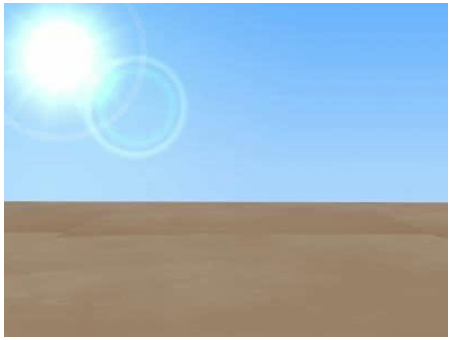
Mesoscale dust storms **Poorly captured by models.**
Some types improve in regional models.



Downslope winds



Gap flow



Dust devils

Haboobs

Dust forecasting models

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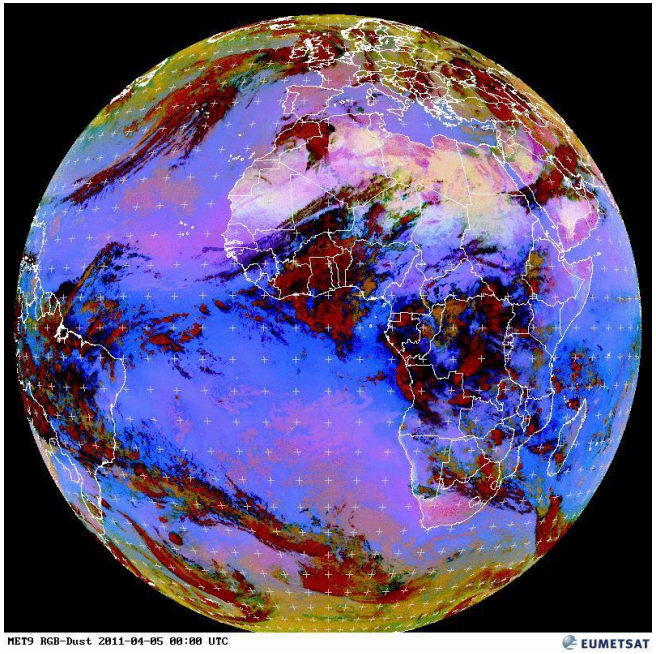
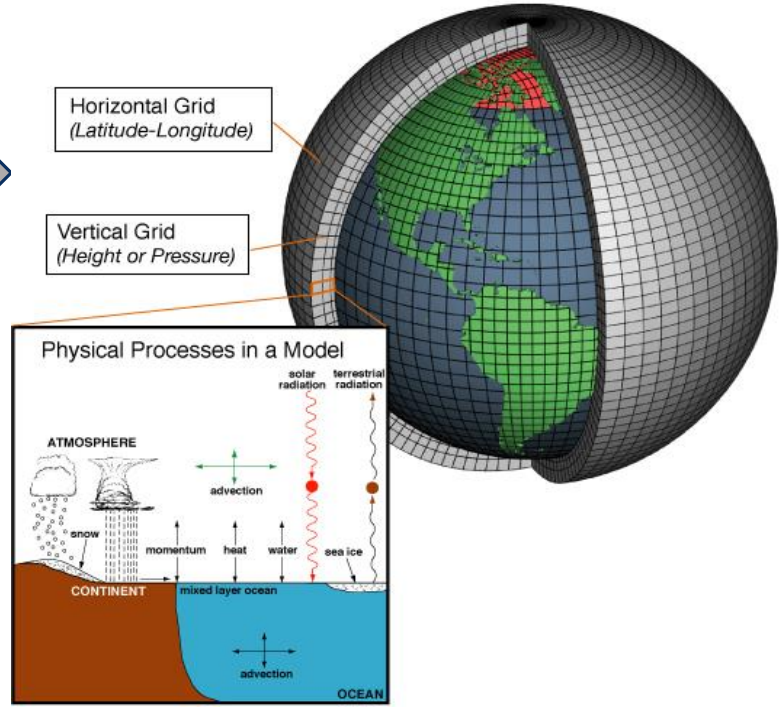
Dust Forecasting models





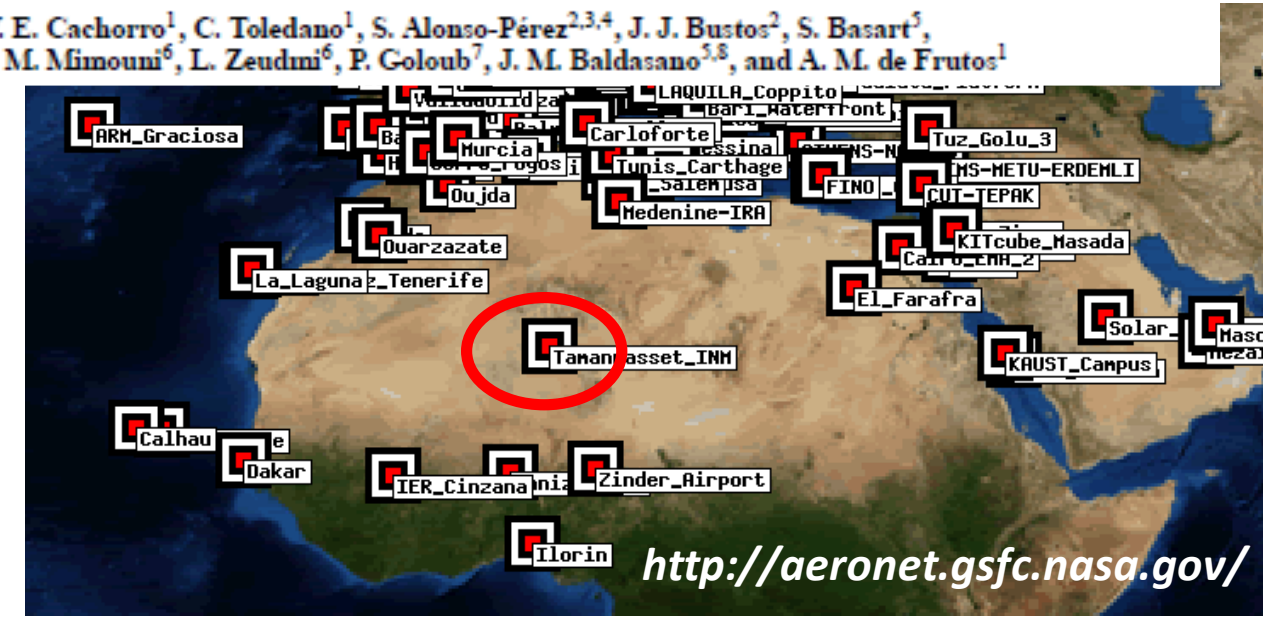
Dust forecasting models

Atmos. Chem. Phys., 14, 11753–11773, 2014
www.atmos-chem-phys.net/14/11753/2014/
doi:10.5194/acp-14-11753-2014

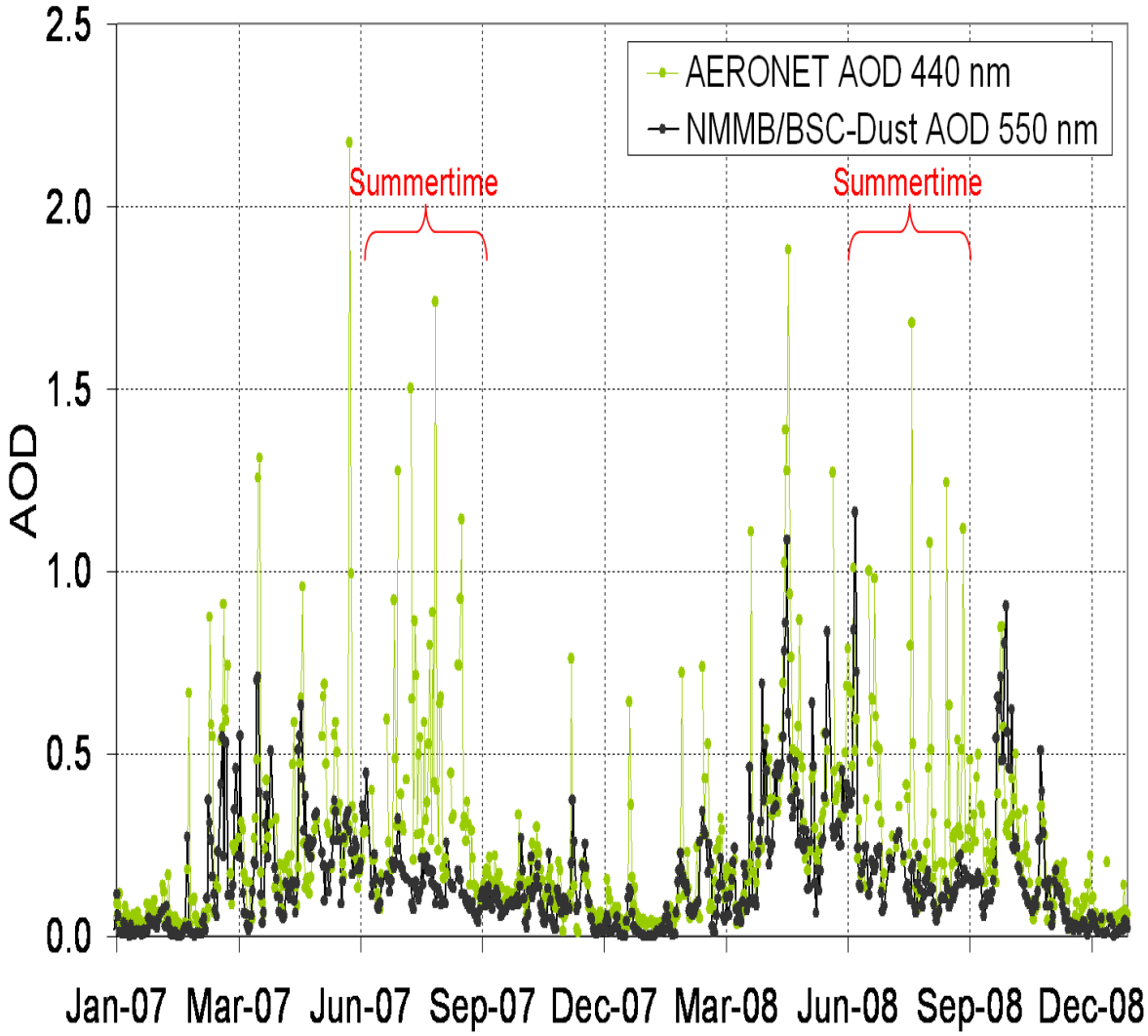
Atmospheric Chemistry and Physics
Open Access

Aerosol characterization at the Saharan AERONET site Tamanrasset

C. Guirado[1,2], E. Cuevas[2], V. E. Cachorro[1], C. Toledano[1], S. Alonso-Pérez[2,3,4], J. J. Bustos[2], S. Basart[5], P. M. Romero[2], C. Camino[2], M. Mimouni[6], L. Zeudmi[6], P. Goloub[7], J. M. Baldasano[5,8], and A. M. de Frutos[1]

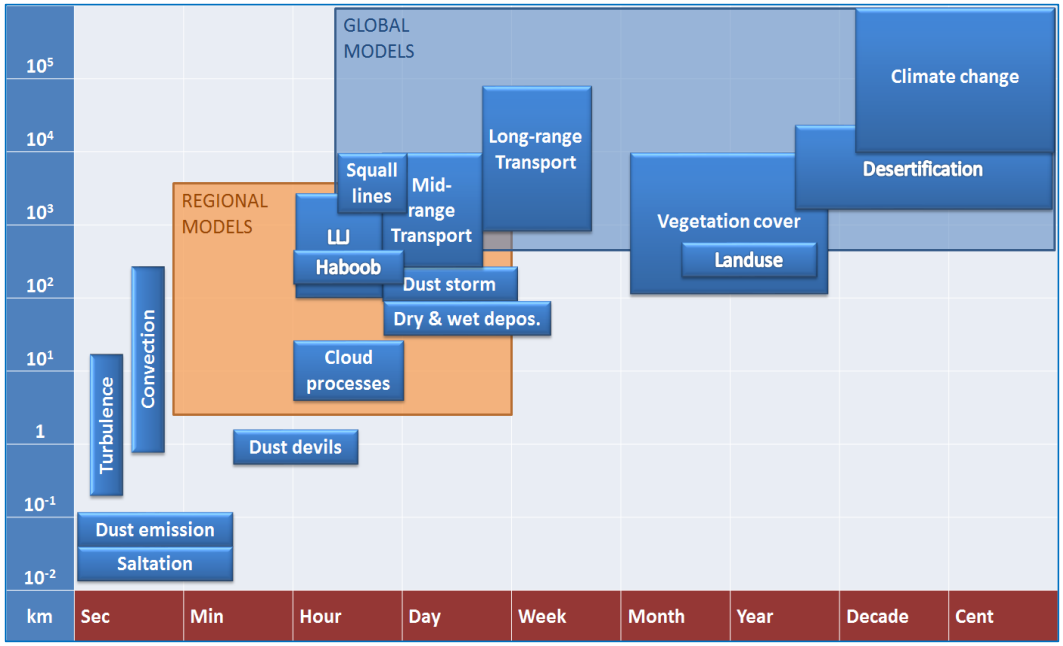


Dust forecasting models



Extracted from Guirado et al. (2014, ACP)

Dust forecasting models



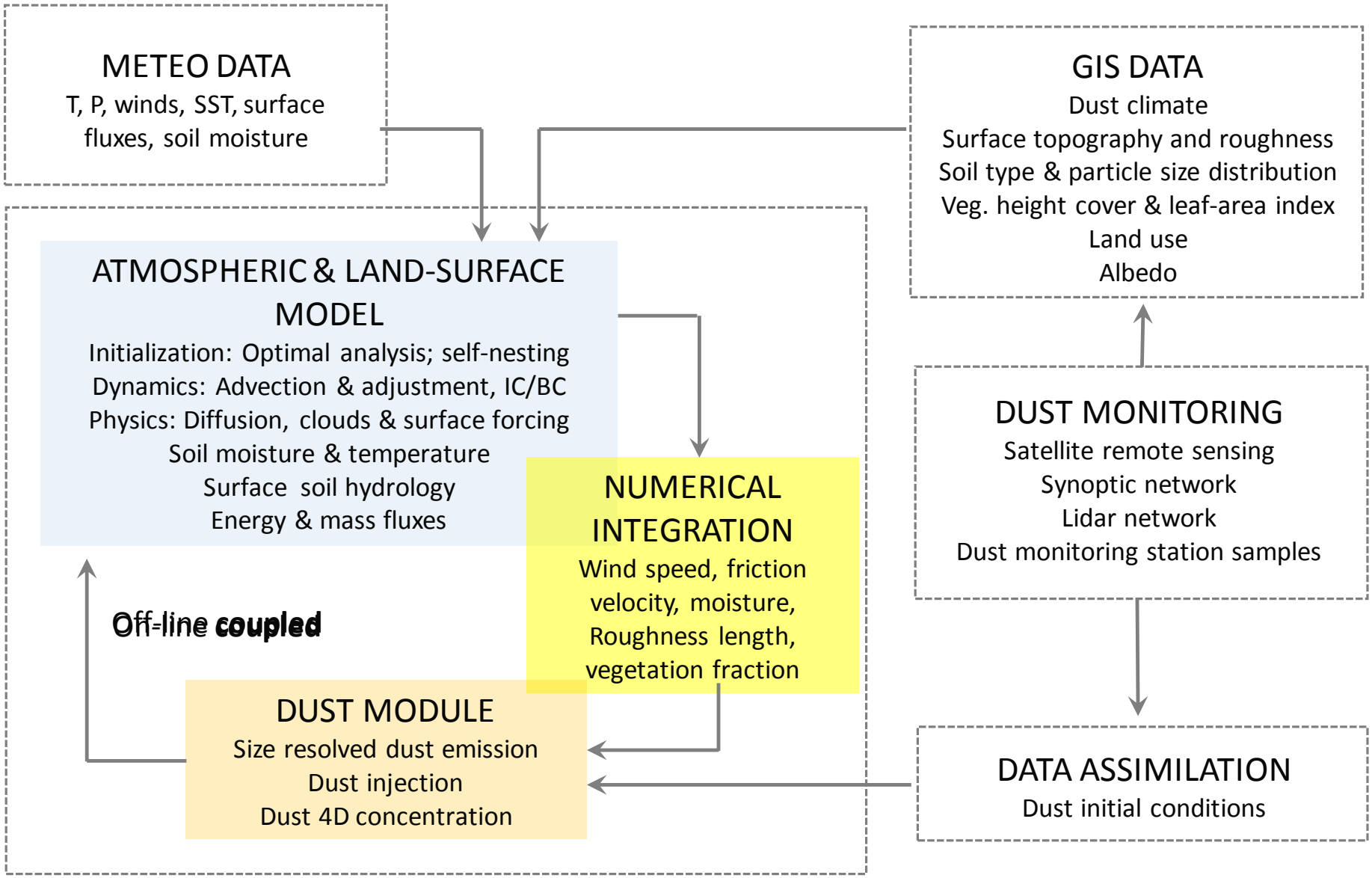
- Dust processes span over five orders of magnitude in space and time. **Dust transport** is a global phenomenon. However, **dust emission** is a threshold phenomenon, sporadic and spatially heterogeneous, that is locally controlled on small spatial and temporal scales.

- To correctly describe and quantify the dust cycle, one needs to understand equally well local-scale processes such as saltation and entrainment of individual dust particles as well as large-scale phenomena such as mid- and long-range transport.

Accurate representation of dust sources and sinks is critical for providing realistic magnitudes and patterns of atmospheric dust fields.

Adapted from Shao (2011)

Dust forecasting models



Desert dust soil types

Main landscapes of the North Africa (Photos from Callot et al. 2000) :

A) Central part of Saharan Atlas. In the background, mountains, and in front, an overgrazed plain;

B) Northern part of Saharan Atlas. Esparto grass steppe degraded by a strong anthropic action. The sandy soil disappears, denuding the sandstone substratum;

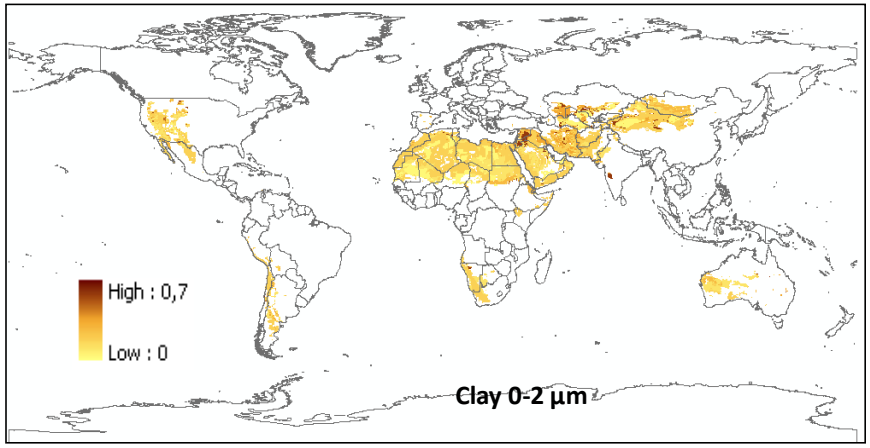
C) The Great Hamada south-west of El-Abiodh-Sidi-Cheikh;

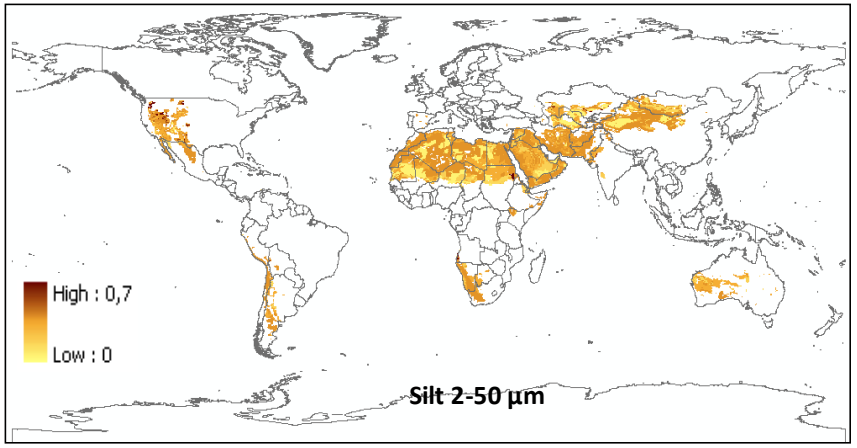
D) Daïa in the Mechfar, at Hassi Cheikh well;

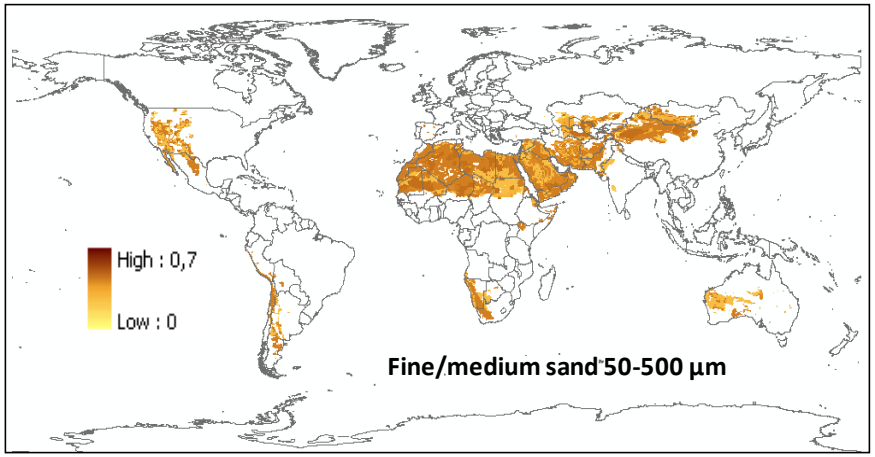
E) North-east of the Great Western Erg: coarse sand interdune corridor with deflation cauldron and palaeolake deposits;

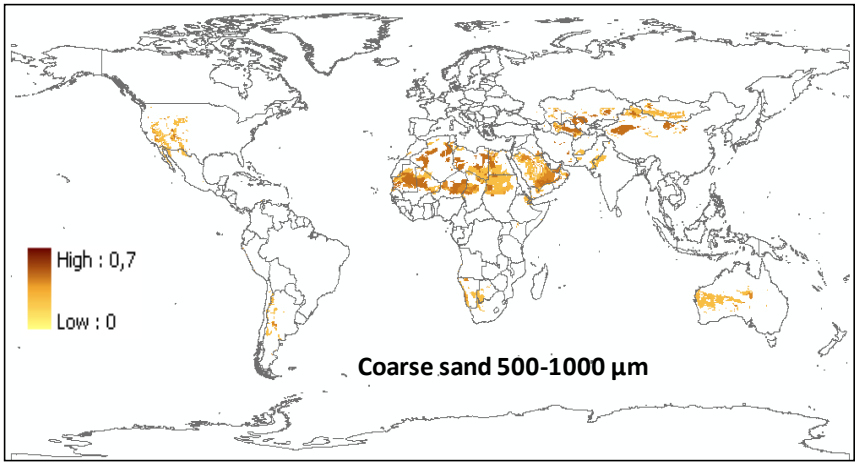
F) North-east of the Great Western Erg: great coarse sand dome dunes, covered by fine sand active dunes.

Soil size distribution derived from soil texture





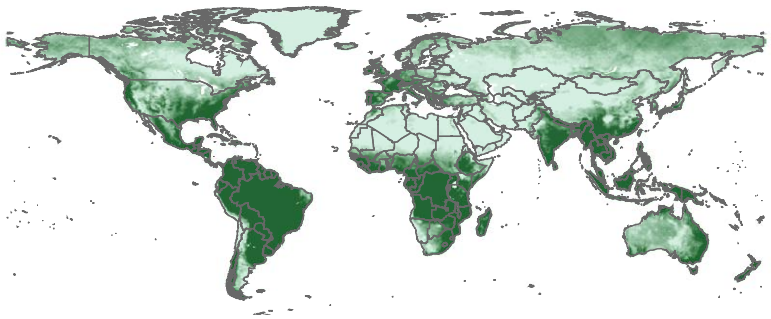




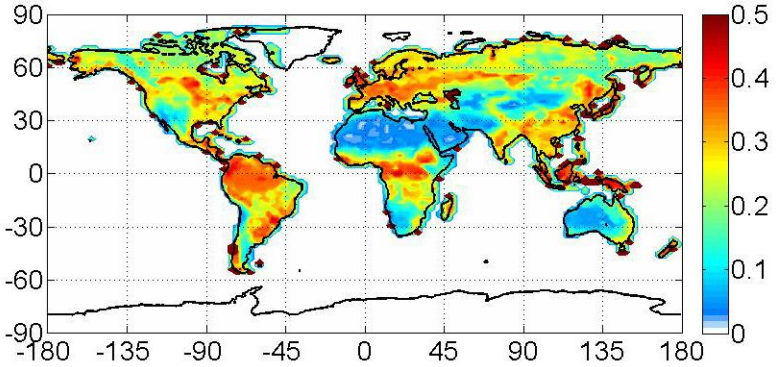
Four top soil texture classes according STASGO-FAO 1km database are converted to 4 parent soil size categories following Tegen et al. [2002].

Vegetation, roughness, soil moisture

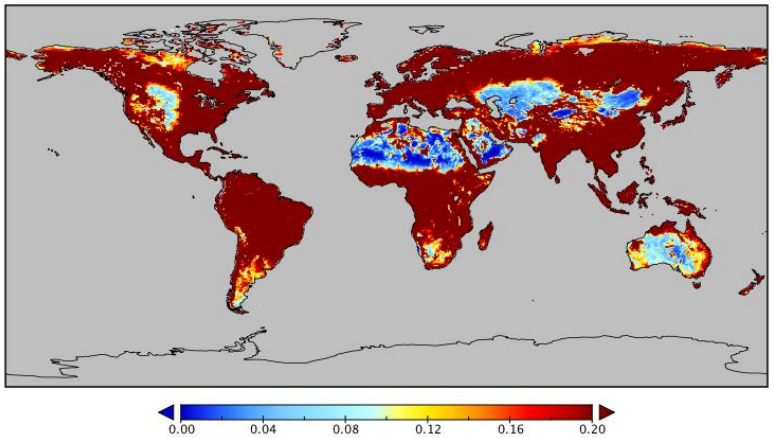
Vegetation fraction
(MODIS)



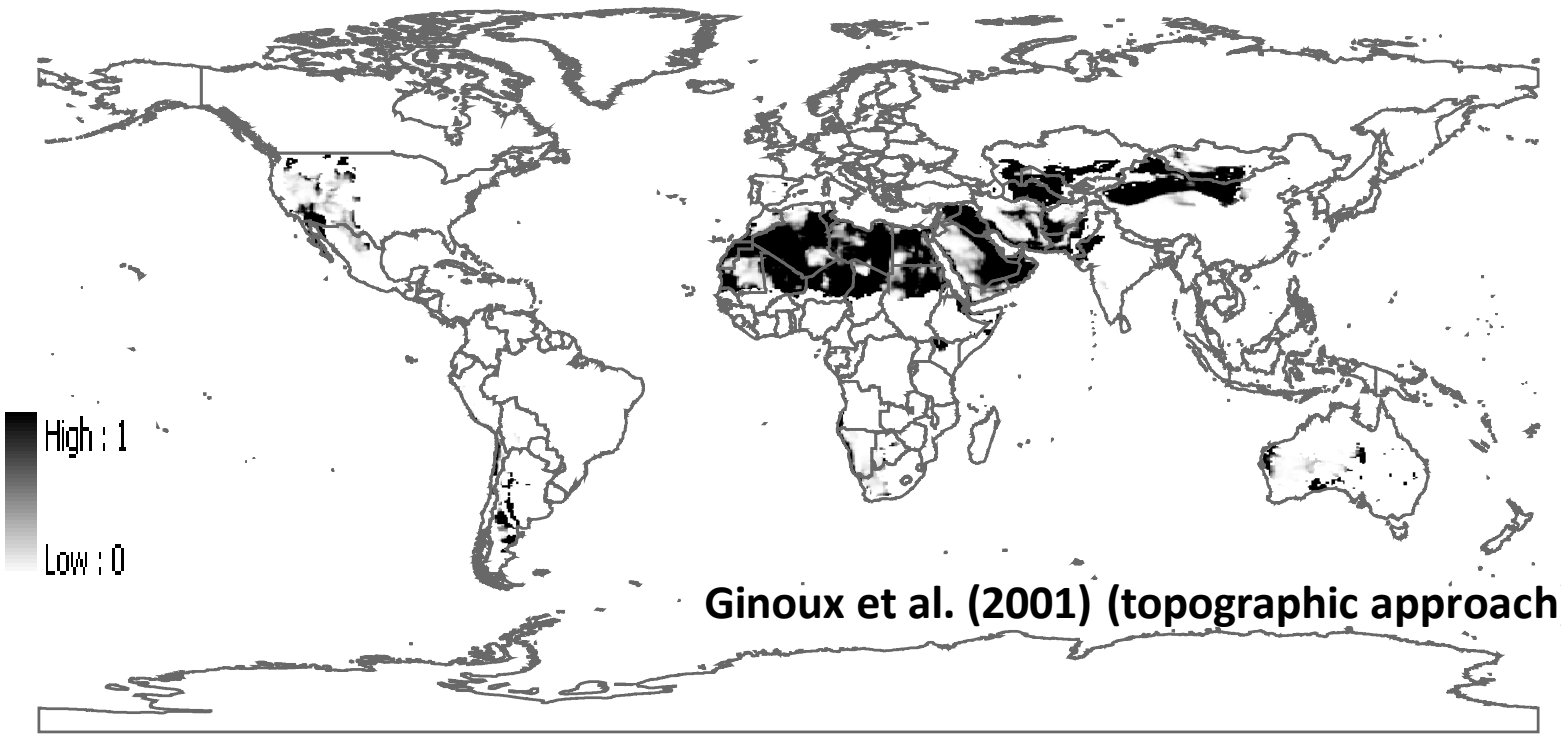
Soil moisture
(model based)



Roughness length
(ASCAT + PARASOL)



Source mapping: why?



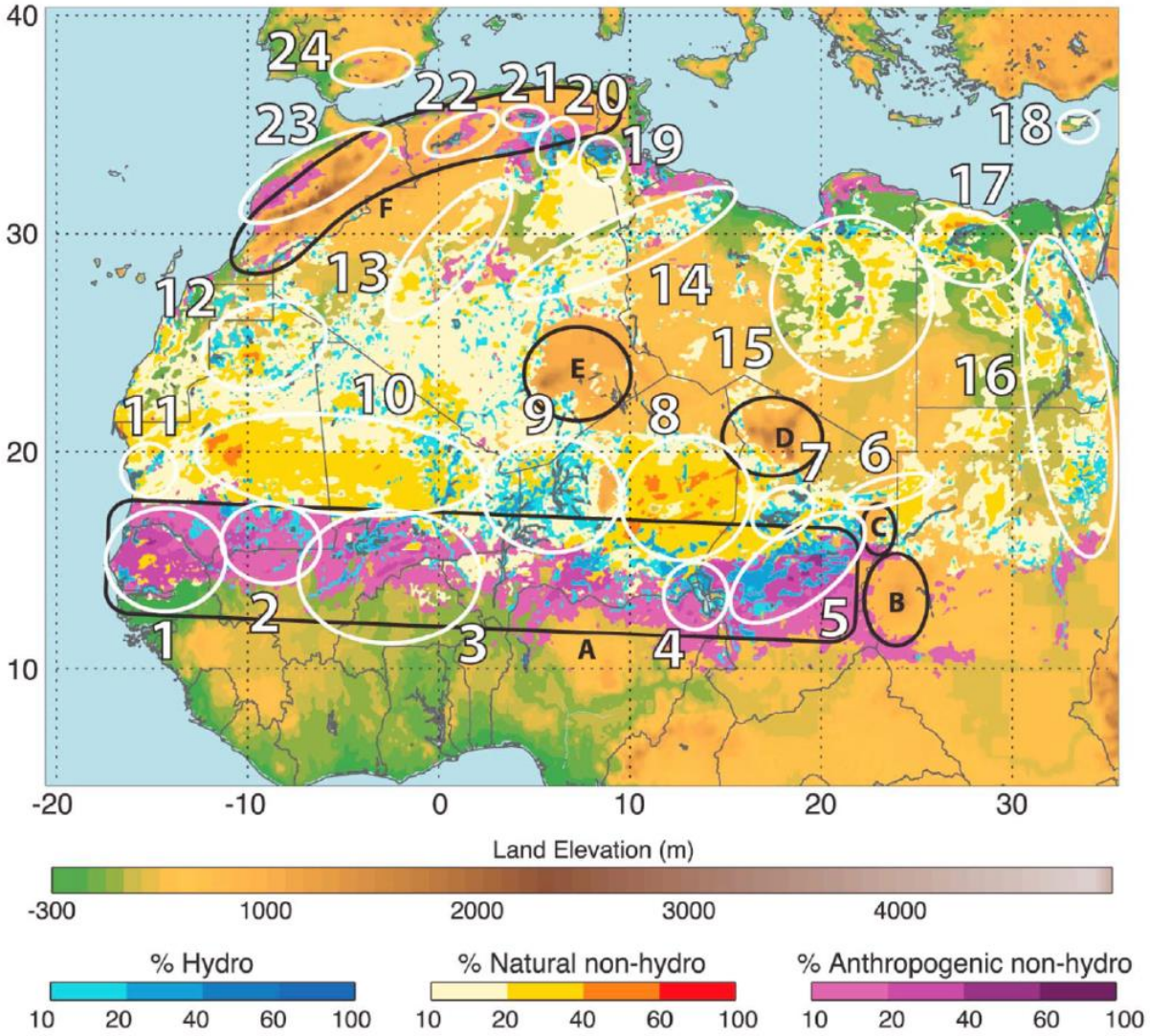
Ginoux et al. (2001) (topographic approach)

$$S = \left(\frac{z_{max} - z_i}{z_{max} - z_{min}} \right)^5$$

S: probability to have accumulated sediments in the grid cell i of altitude zi

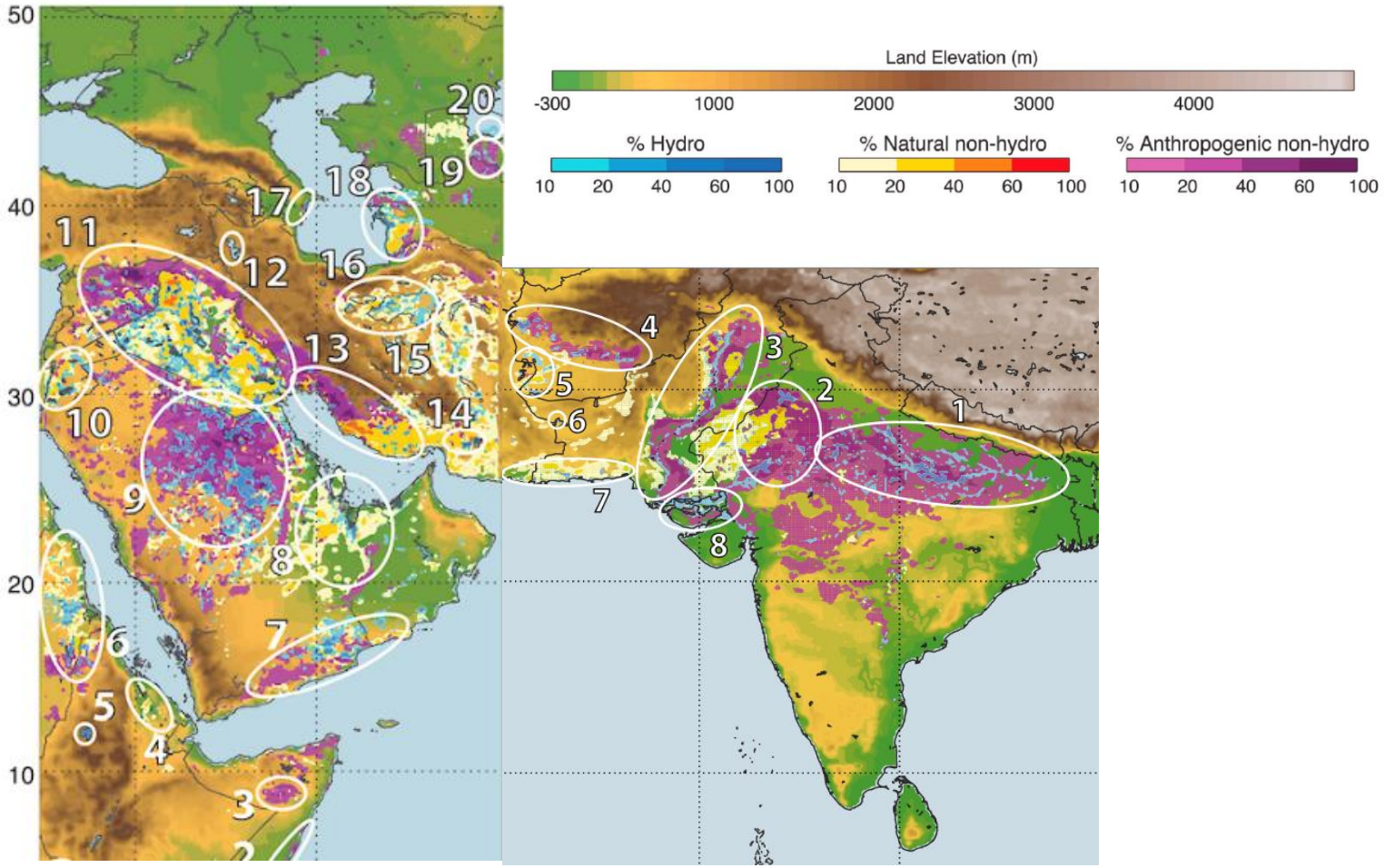
best fit with the sources identified by Prospero et al. 2000

Natural and anthropogenic dust sources



(Ginoux et al. 2012)

Natural and anthropogenic dust sources



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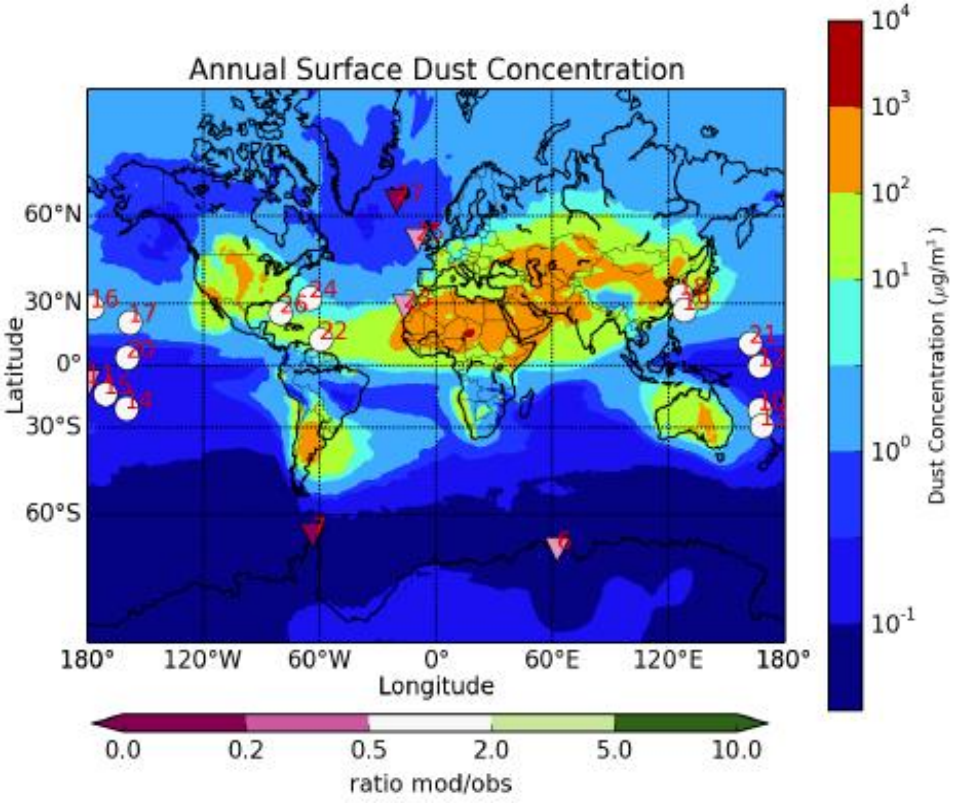
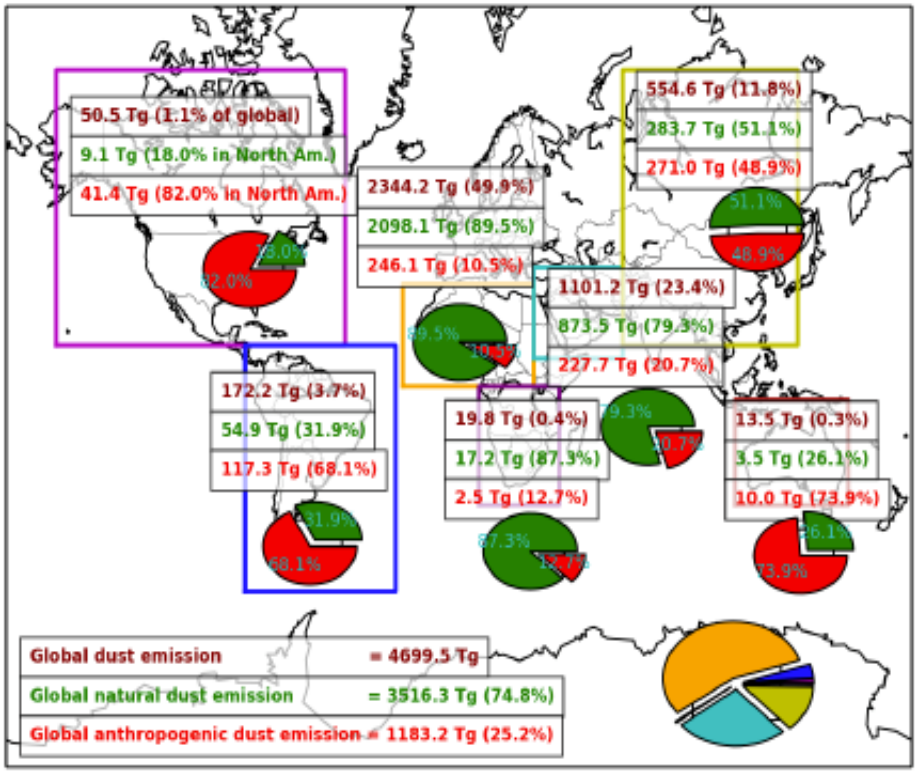
(Ginoux et al. 2012)

Current quantification natural vs. anthropogenic





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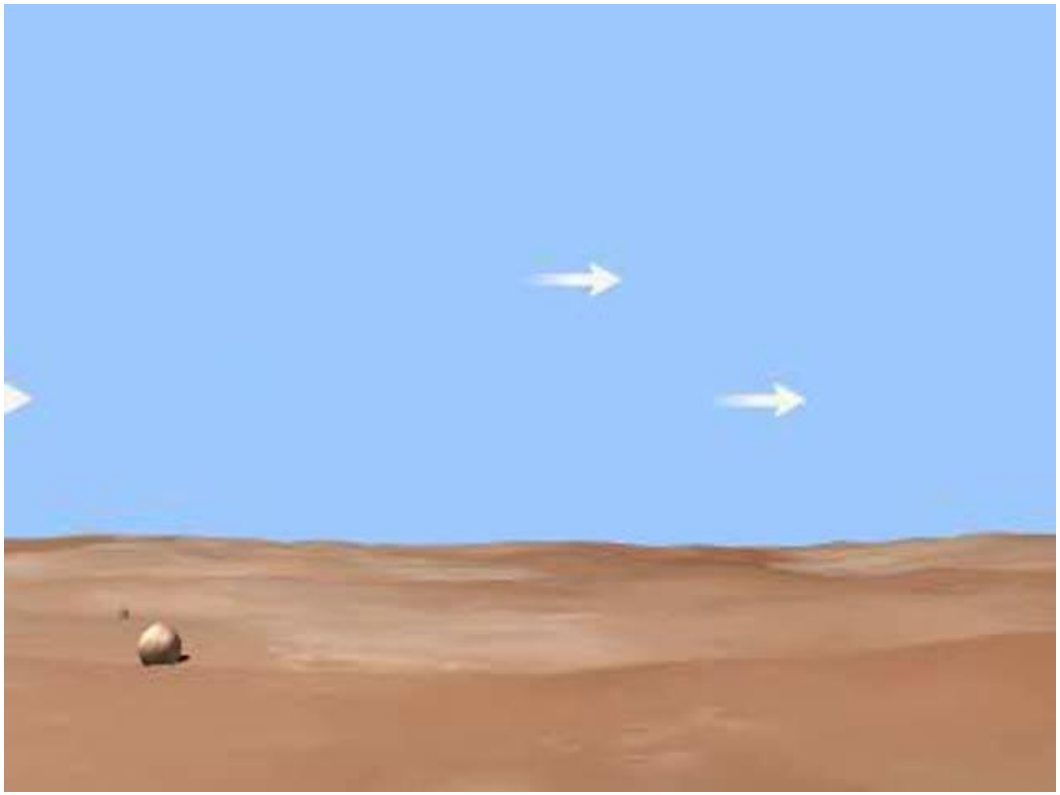
Perez García-Pando et al., in prep

Major challenge for modeling

Dust emission mechanisms

- Complex physical process involving entrainment of soil particles by the surface winds.



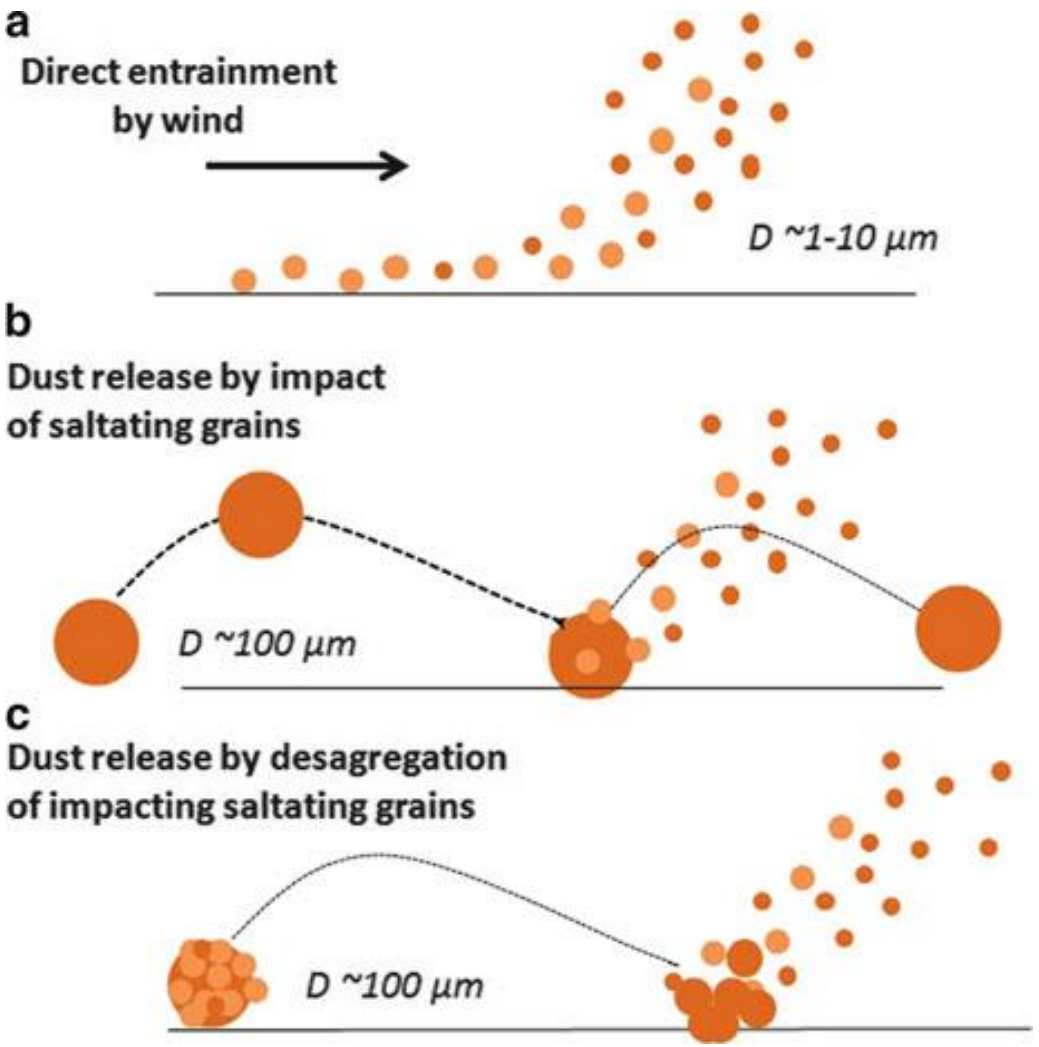
- Creep or rolling motion of the largest particles (> 500 um)

- Saltation or horizontal motion of large soil grains (sand) (50-500um)

- Suspension of dust (after sandblasting or saltation bombardment) (0.1-50 um)

Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust emission mechanisms



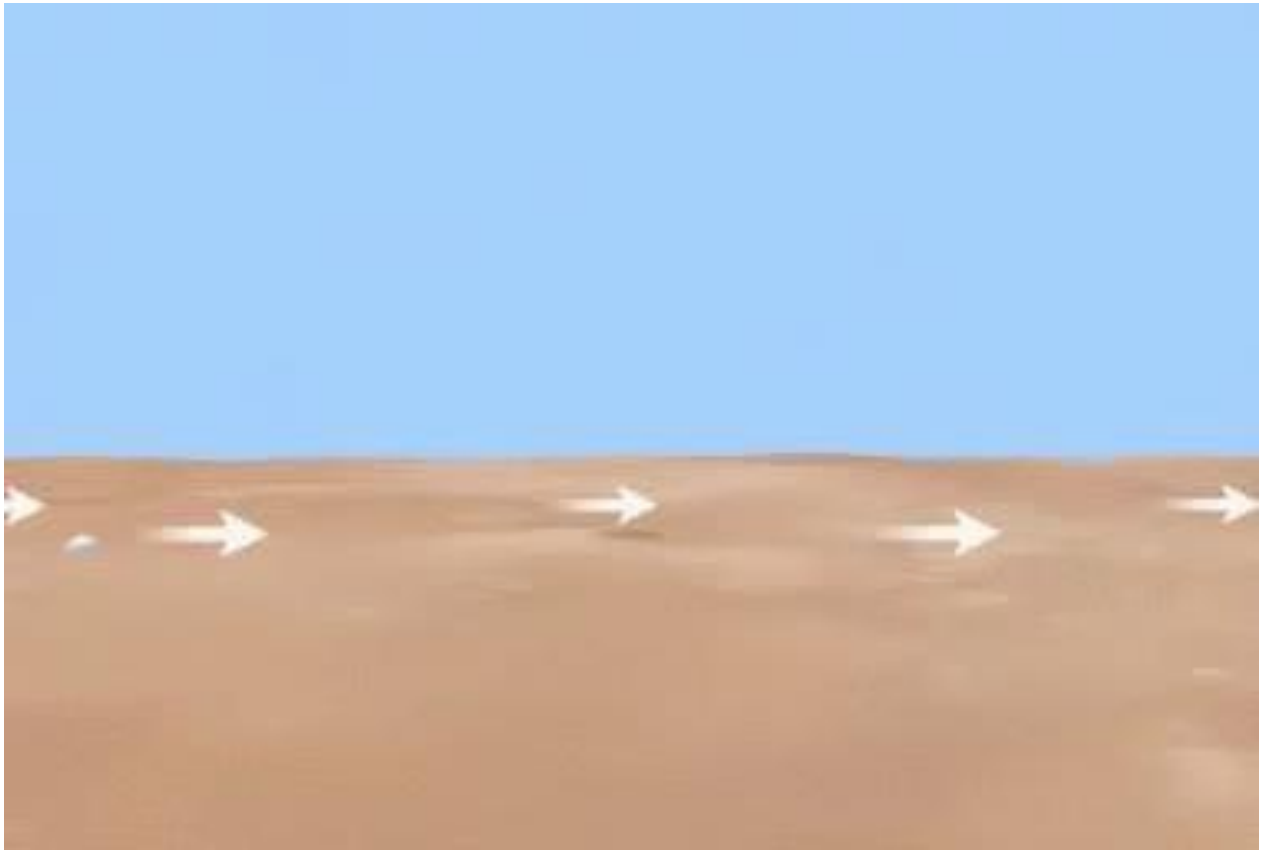
Emitted dust mass

&

Size distribution

Dust dry deposition

Sedimentation and dry deposition



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust wet deposition

Wet scavenging

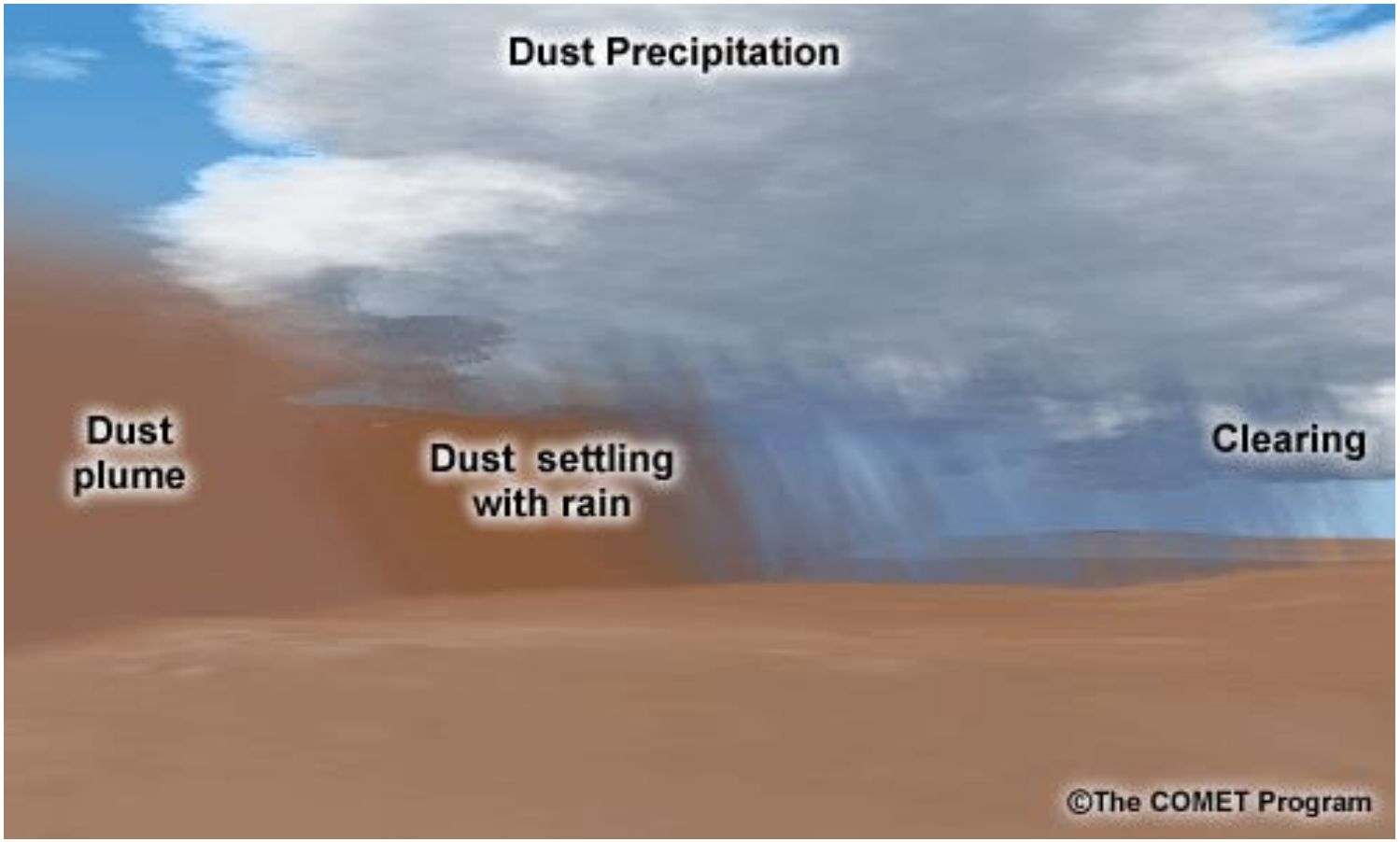
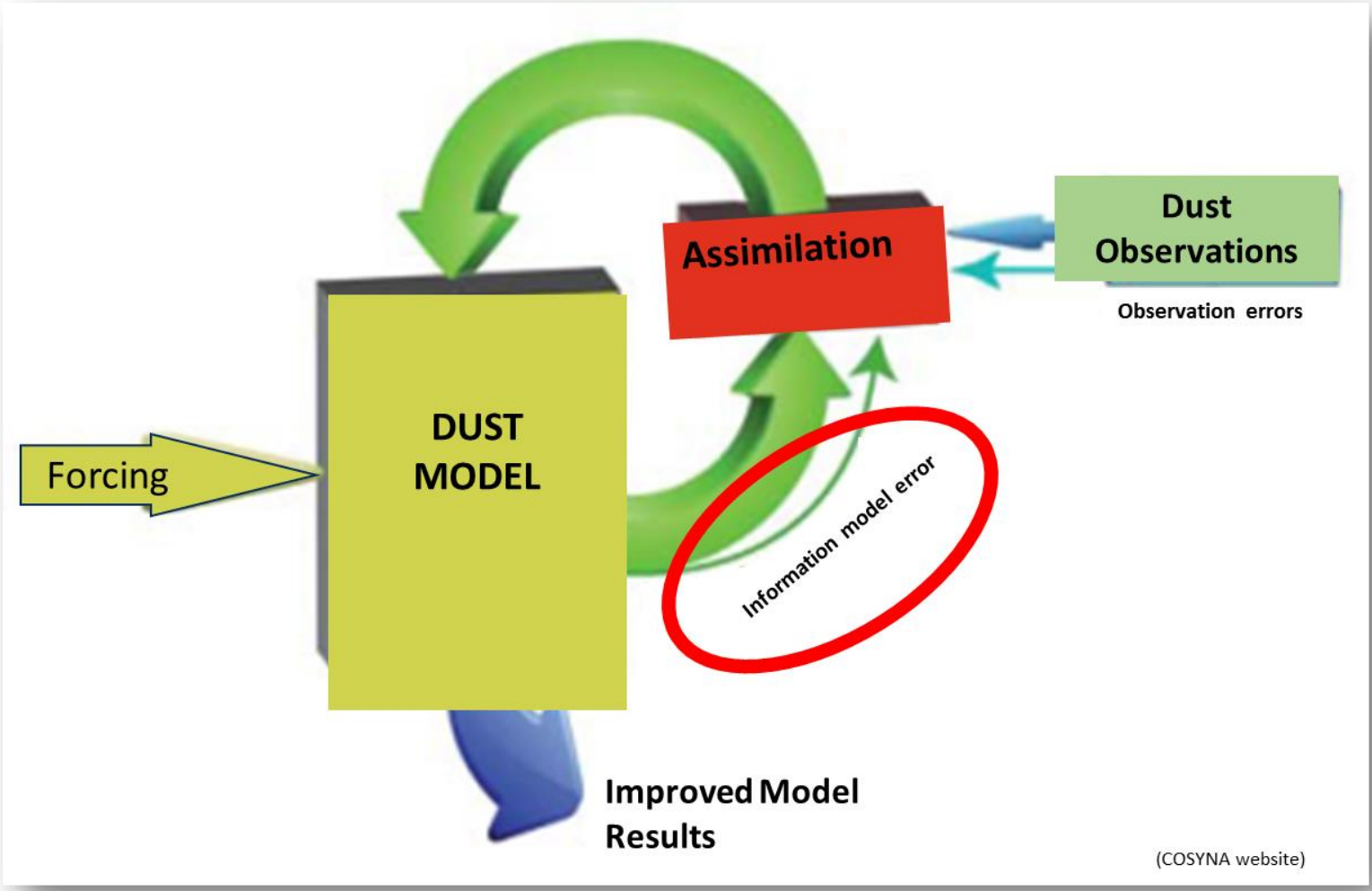


Image from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Data Assimilation



Obtaining the 'best' estimate of current atmospheric dust conditions **(analysis)**
Creating datasets describing the recent history of dust in the atmosphere **(reanalysis)**

Dust forecasting models

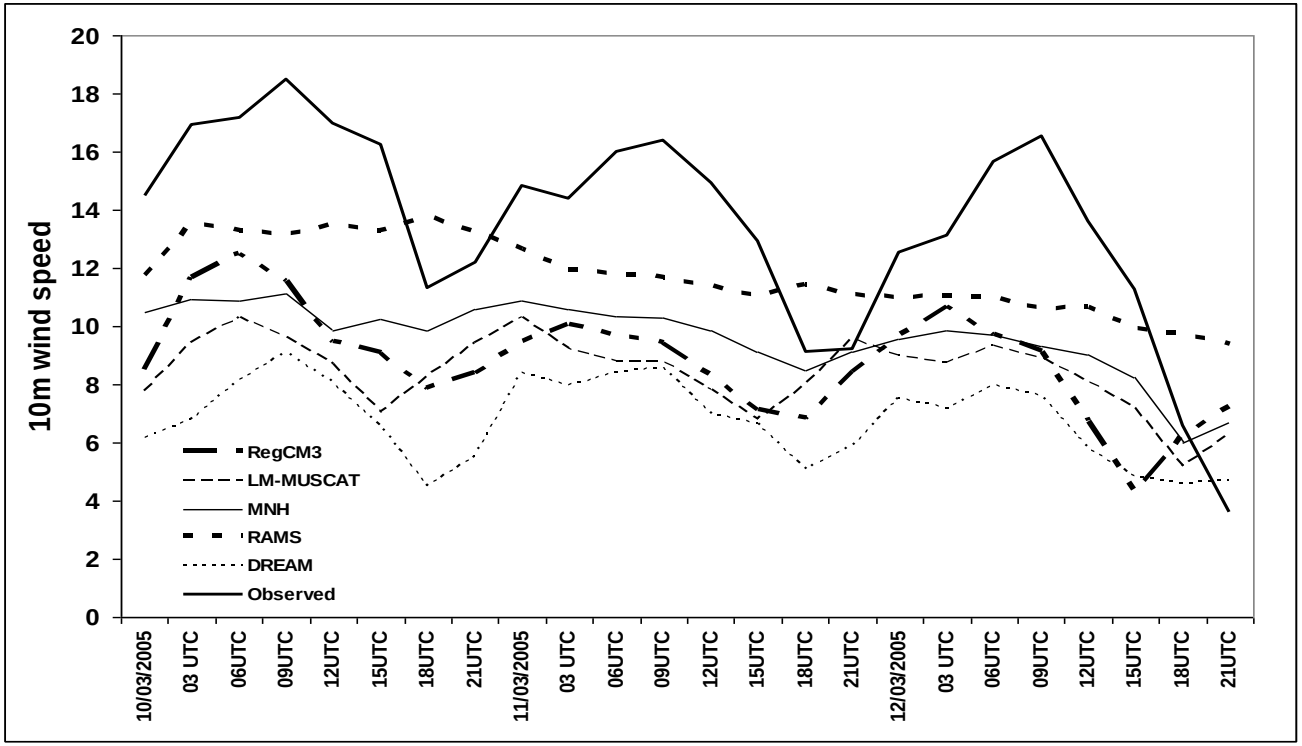
Main differences between dust models

1. *Meteorological driver*
2. *Meteorological input files IBC*
3. *Emission scheme*
4. *Geographic-information database (source mask)*
5. *Land-surface scheme*
6. *Dry deposition scheme*
7. *Wet depositioon scheme*
8. *Spatio-temporal resolution*
9. *Data assimilation*
10. *….*

Dust forecasting models

Experimental campaigns: BODEX 2005 (Todd et al. 2008, JGR)

First regional model intercomparison in the Bodélé hot spot



Strong differences between models!!!! → **Meteorology** and **emission scheme**

Modeling the dust cycle at BSC: From R&D to operational

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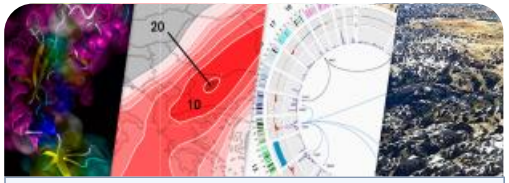
BSC objectives

Supercomputing services to Spanish and EU researchers



R&D in Computer, Life, Earth and Engineering Sciences

PhD programme, technology transfer, public engagement

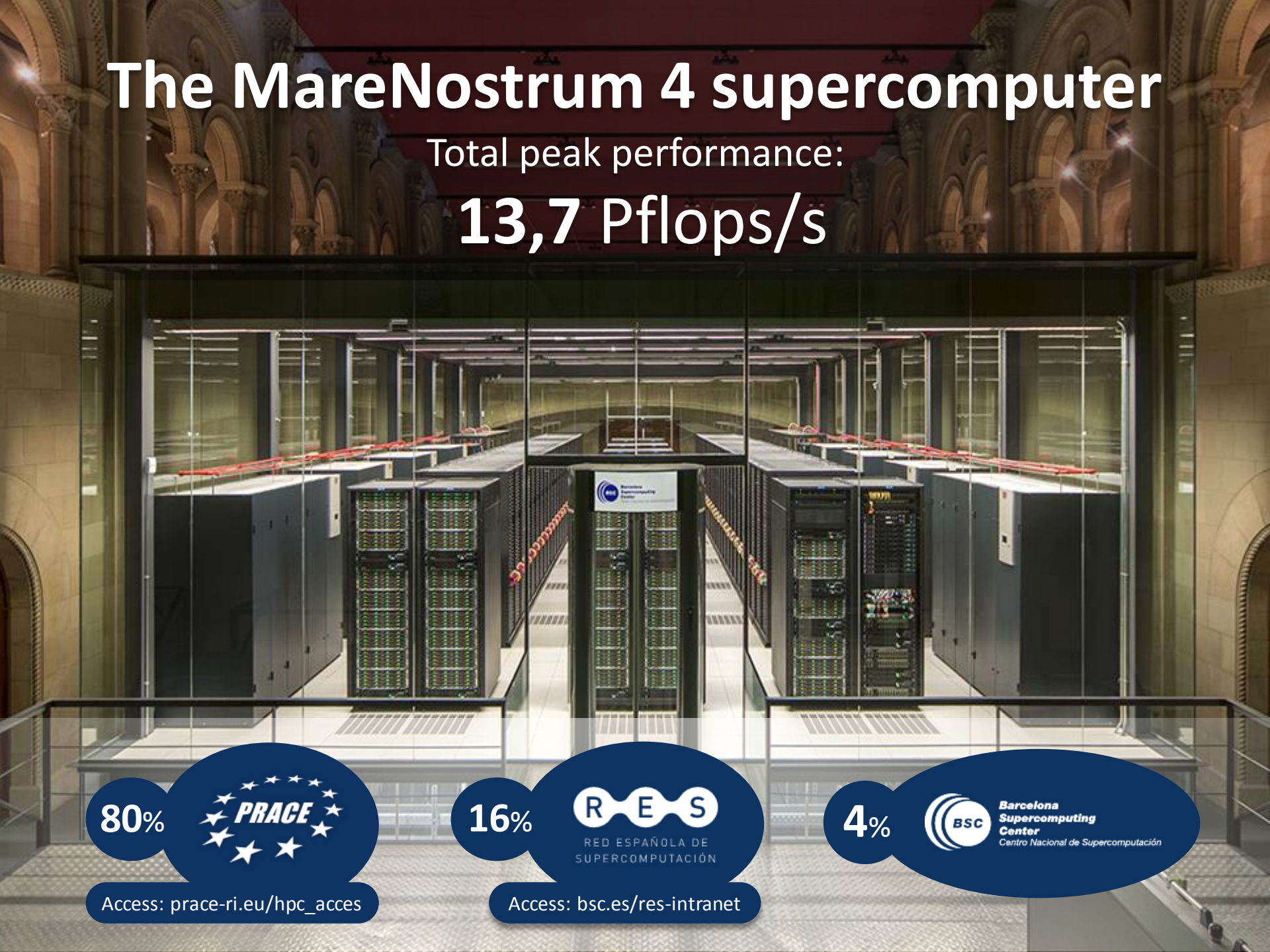
BSC is a consortium that includes

Spanish Government	60%	GOBIERNO DE ESPAÑA · MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD
Catalonian Government	30%	Generalitat de Catalunya Departament d'Empresa i Coneixement
Univ. Politècnica de Catalunya (UPC)	10%	UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

The MareNostrum 4 supercomputer

Total peak performance:

13,7 Pflops/s



80% PRACE

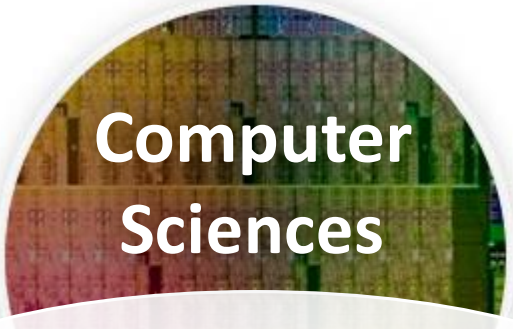
Access: prace-ri.eu/hpc_acces

16% RES RED ESPAÑOLA DE SUPERCOMPUTACIÓN

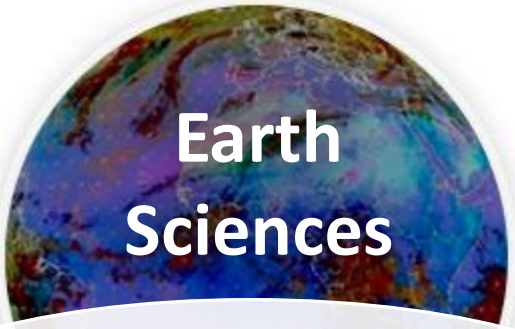
Access: bsc.es/res-intranet

4% BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

Mission of BSC Scientific Departments



To influence the way machines are built, programmed and used: programming models, performance tools, Big Data, computer architecture, energy efficiency



To develop and implement global and regional state-of-the-art models for short-term air quality forecast and long-term climate applications

To understand living organisms by means of theoretical and computational methods (molecular modeling, genomics, proteomics)

To develop scientific and engineering software to efficiently exploit super-computing capabilities (biomedical, geophysics, atmospheric, energy, social and economic simulations)

Earth Sciences Department

Environmental modelling and forecasting, with a particular focus on weather, climate and air quality

Modeling **air quality** and **Sand and Dust Storms** Processes from urban to Global and the impacts on weather, health and ecosystems

Research and Forecasts

Climate predictions system from subseasonal-to-decadal forecasts

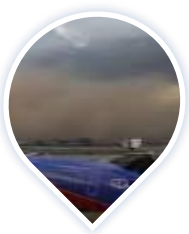
AXA Research Fund

Service Users Sectors


Infrastructures


Solar Energy

Urban development


Transport


Wind Energy


Agriculture


Insurance

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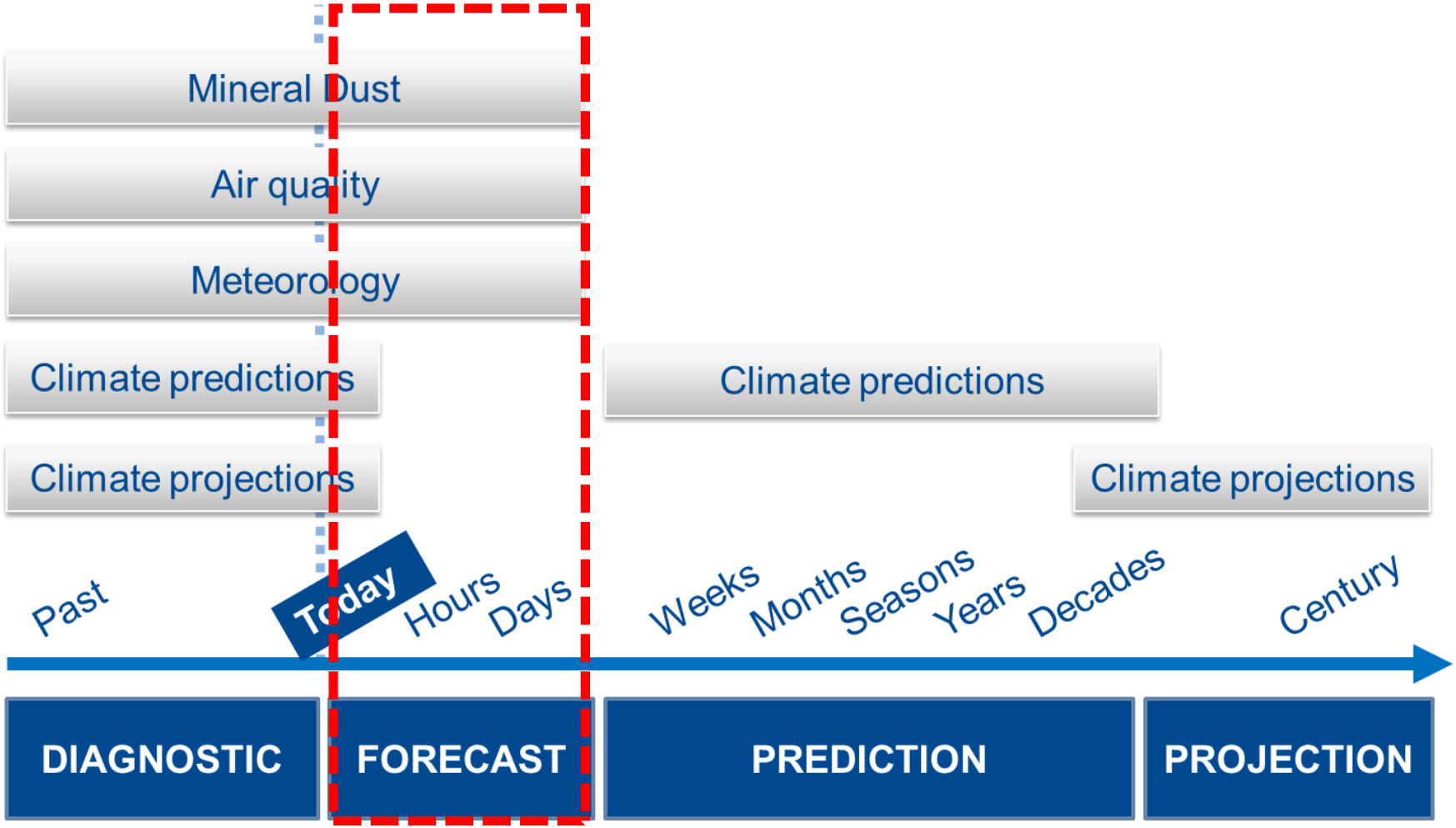
BSC Earth Sciences Department

Enviromental modelling and forecasting



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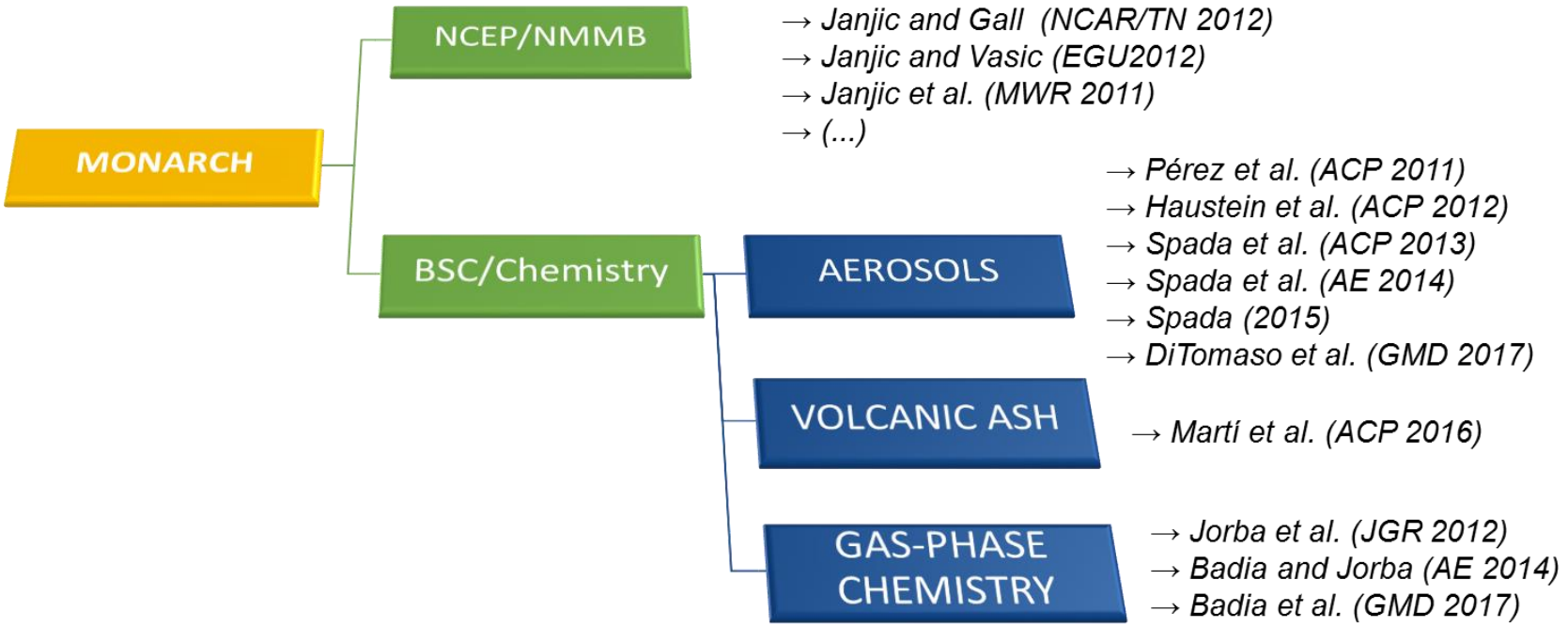
Short-term forecast

The MONARCH model

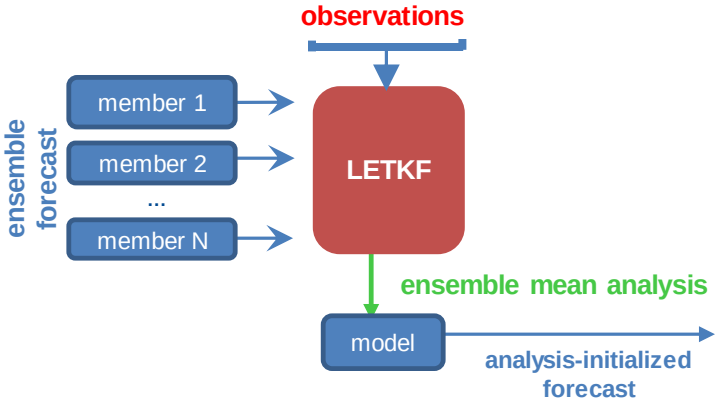
· ***Multiscale***: global to regional (up to 1km) scales allowed
· Fully ***on-line*** coupling: weather-chemistry feedback processes allowed
· Enhancement with a ***data assimilation*** system



Dust module is known as **NMMB/BSC-Dust**

MONARCH - Dust Data Assimilation

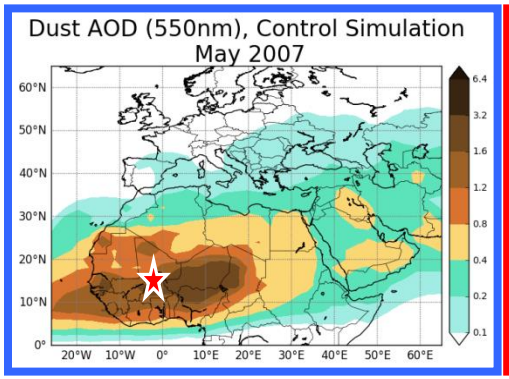
MONARCH coupled with a Local Ensemble Transform Kalman Filter (**LETKF**) for the assimilation of aerosol optical depth observations

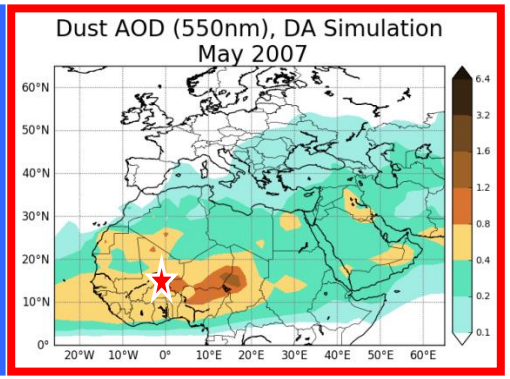


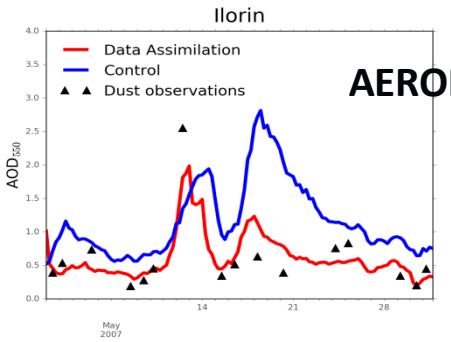
Mineral dust application
The ensemble forecast is based on uncertainties in the dust emission scheme

- vertical flux,
- size distribution at emission
- threshold on friction velocity

(Di Tomaso et al., GMD, 2017)



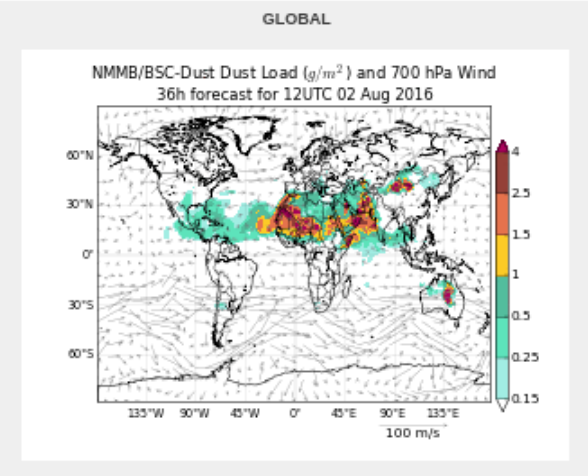


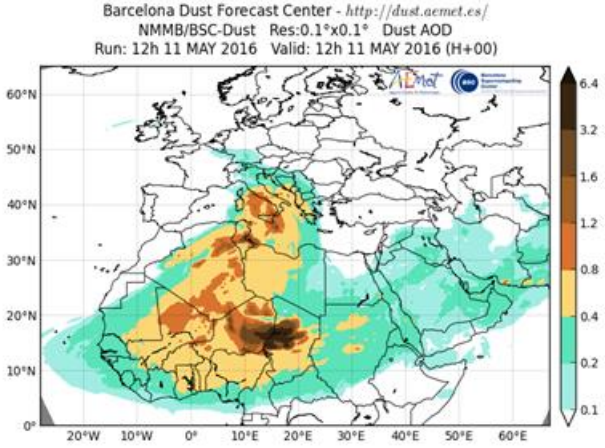


AERONET Validation

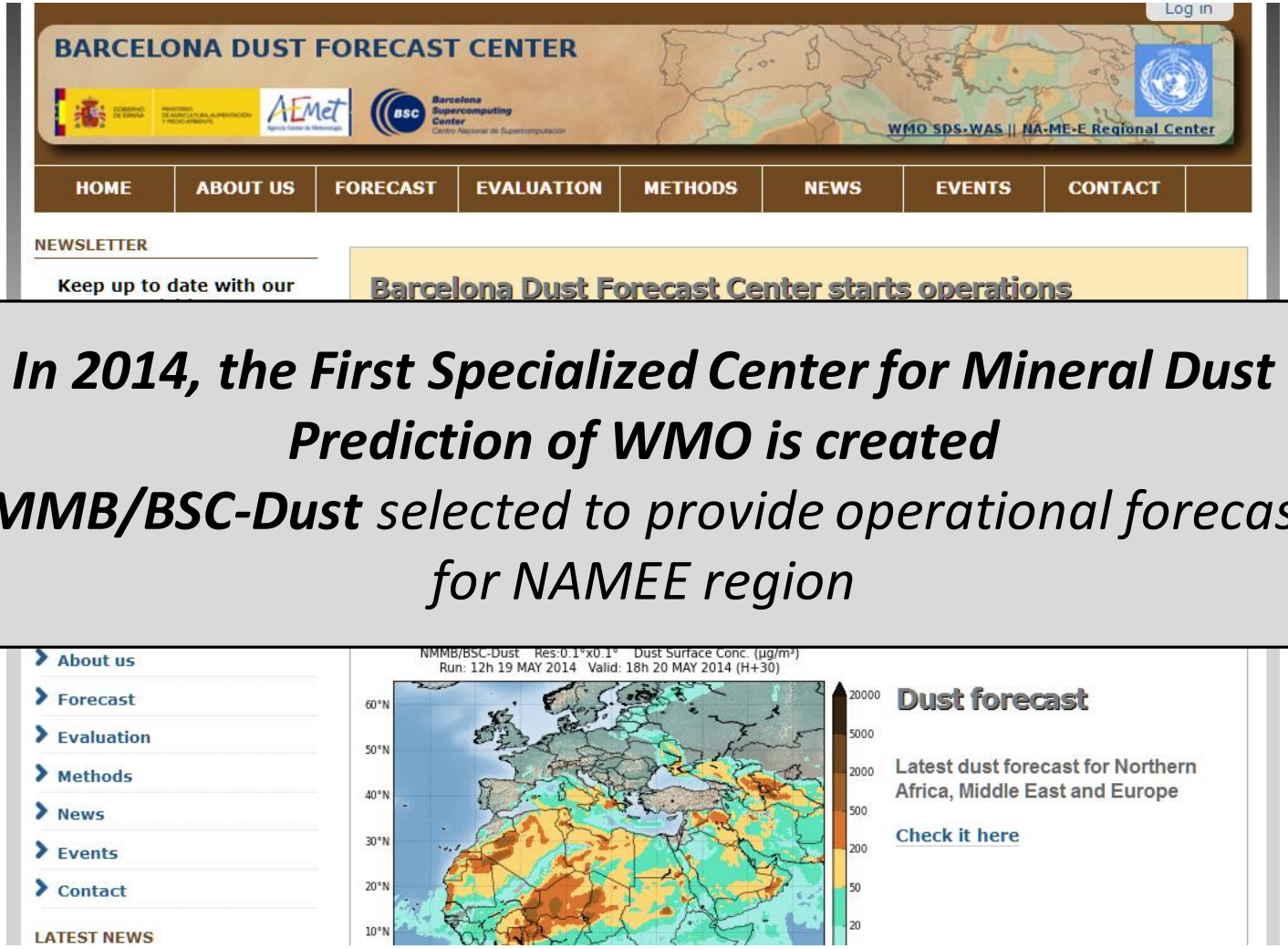
WMO Dust Centers in Barcelona

- **BSC dust operational forecast** (global and regional domains)
  - Contribution to the SDS-WAS (regional) and ICAP (global) multi-model ensembles
- **WMO Dust Regional Centers**
  - **Barcelona Dust Forecast Center.** First specialized WMO Center for mineral dust prediction. Started in 2014 - **Operational**
    - *http://dust.aemet.es*
    - *@Dust_Barcelona*
  - **SDS-WAS**. North Africa, Middle East and Europe Regional Center. Started in 2010 – **Research**
    - *http://sds-was.aemet.es*





Barcelona Dust Forecasting Center



In 2014, the First Specialized Center for Mineral Dust Prediction of WMO is created

NMMB/BSC-Dust *selected to provide operational forecasts for NAMEE region*

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AEMet
Agencia Estatal de Meteorología

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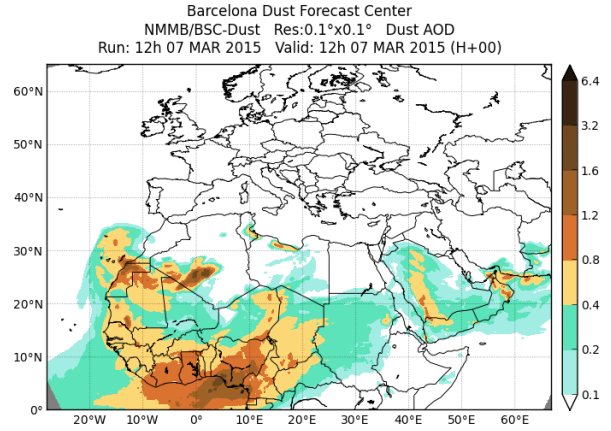
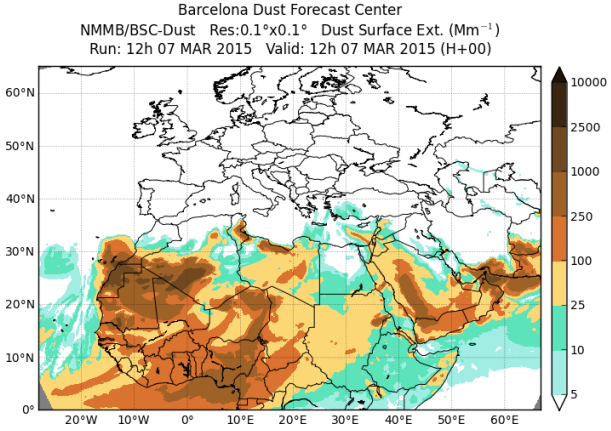
http://dust.aemet.es/

Barcelona Dust Forecasting Center

- **Operational products:**
  - Dust Optical Depth at 550nm
  - Dust Dry Deposition
  - Dust Load
  - Dust Surface Concentration
  - Dust Surface Extinction at 550nm
  - Dust Wet Deposition





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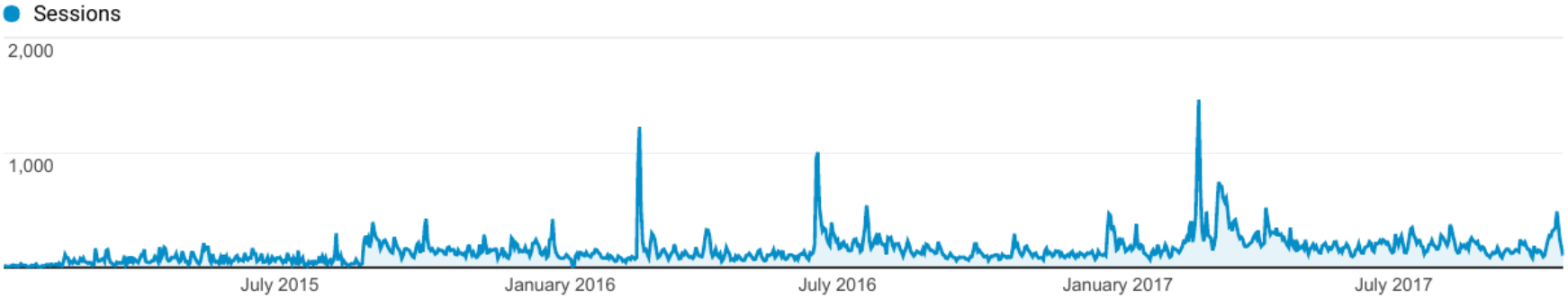
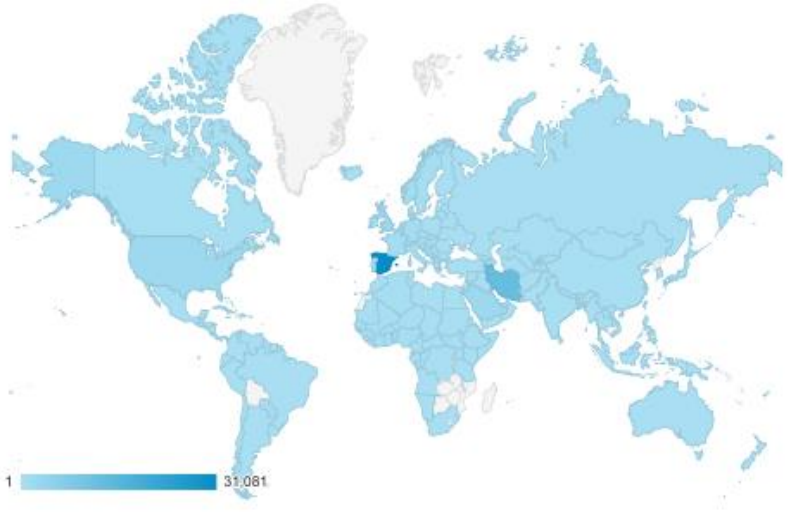
http://dust.aemet.es/

Barcelona Dust Forecasting Center

Website visits (*http://dust.aemet.es/*): 1 January 2015 – 20 October 2017





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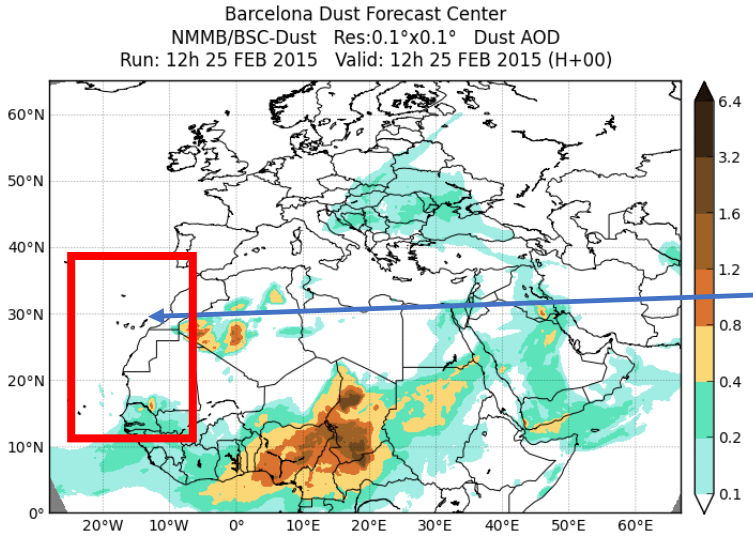
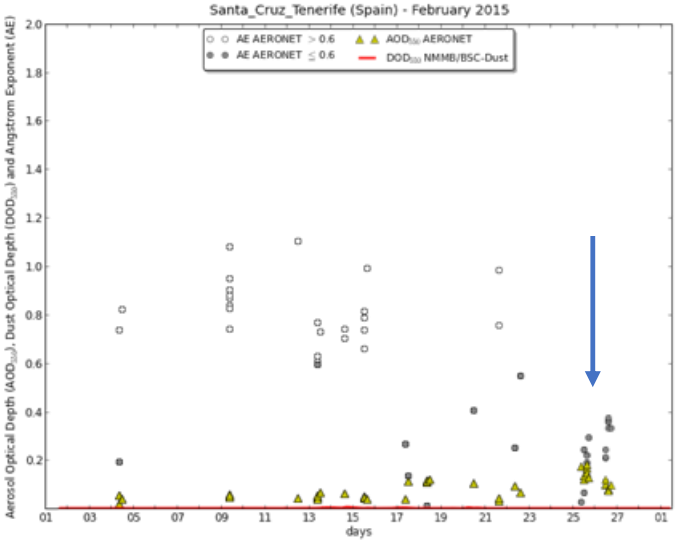
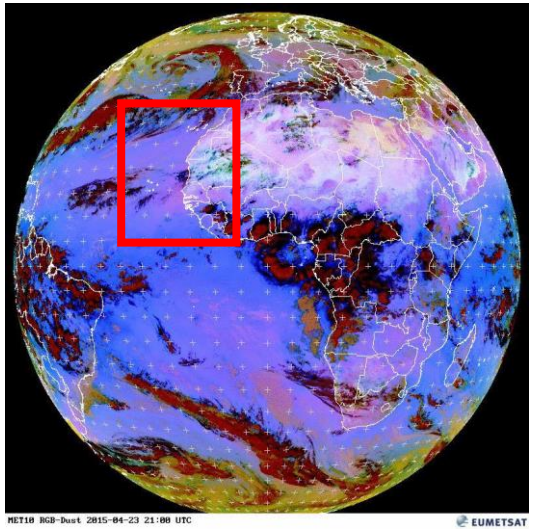
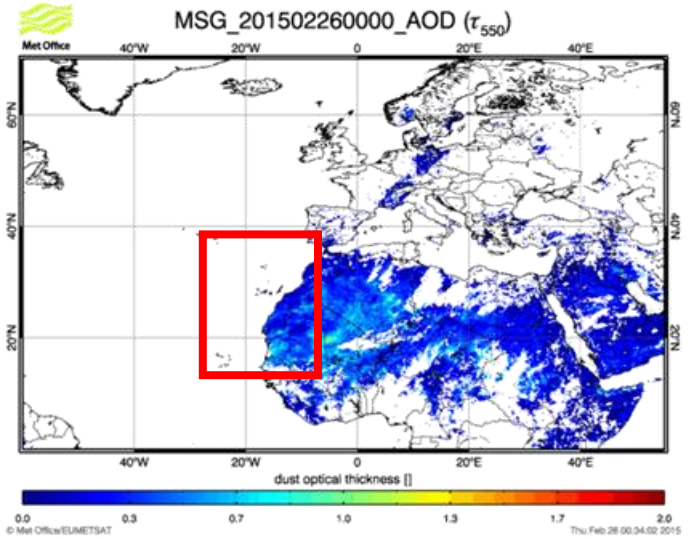
Centro Nacional de Supercomputación
AEMet Agencia Estatal de Meteorología
GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE
AEMet Agencia Estatal de Meteorología

BDFC: Dust event Canary Islands Feb 2015



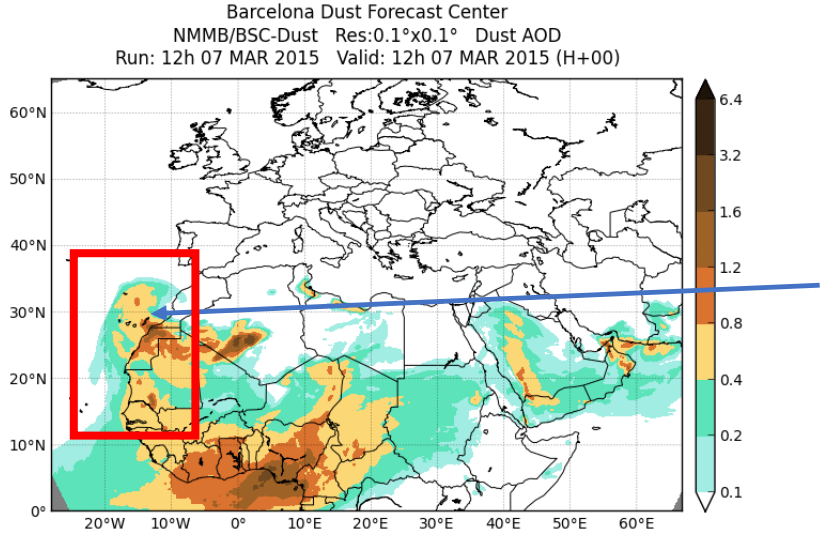


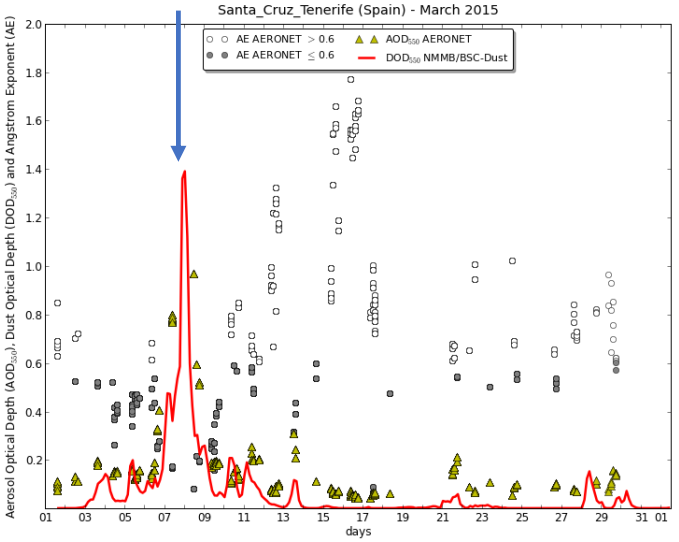


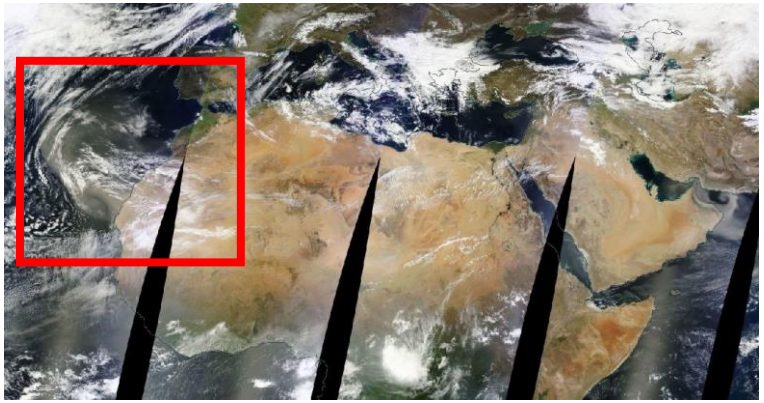


http://dust.aemet.es/

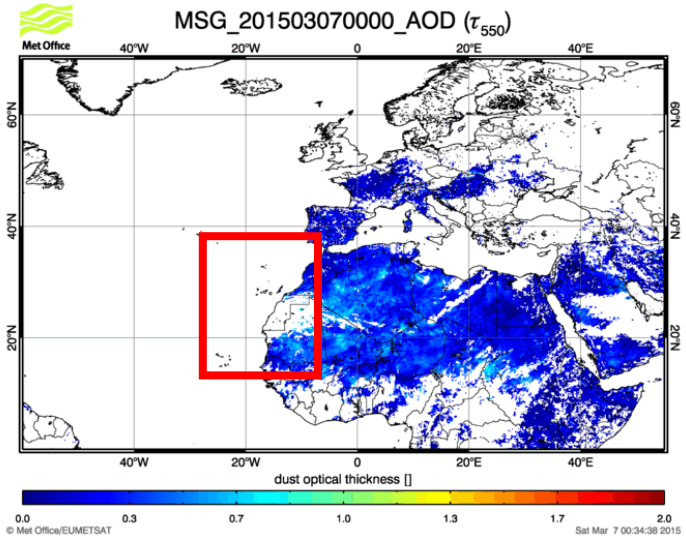
BDFC: Dust event Canary Islands Mar 2015





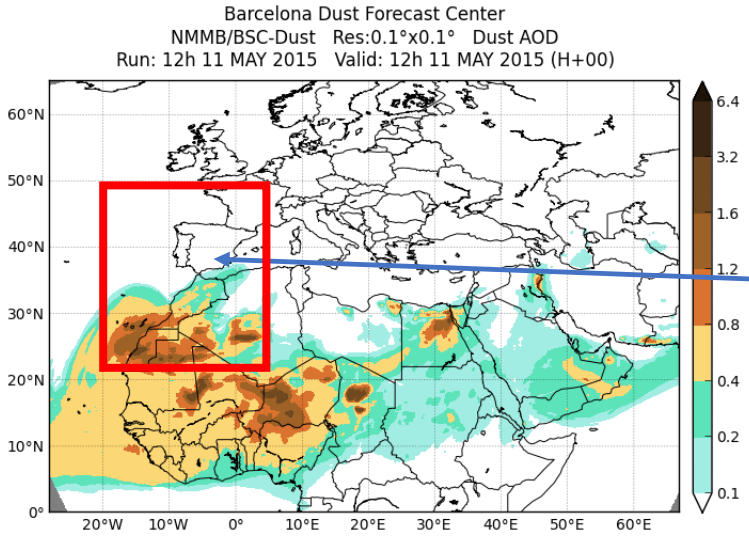


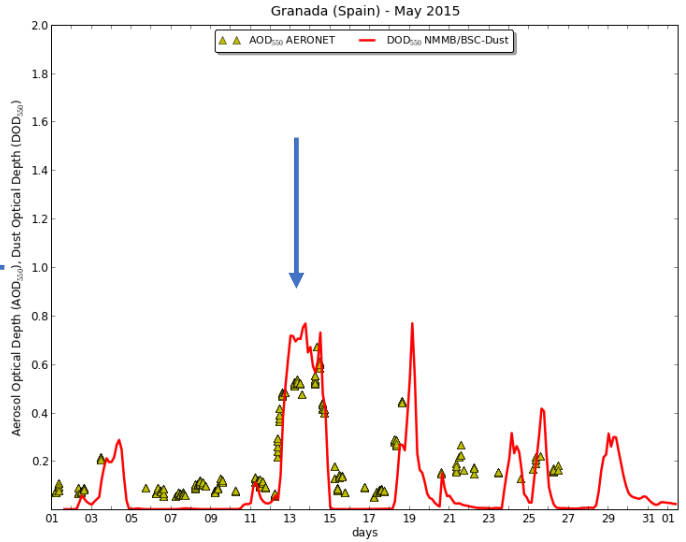
MODIS composite 8th March 2015 from EOSDIS World Viewer

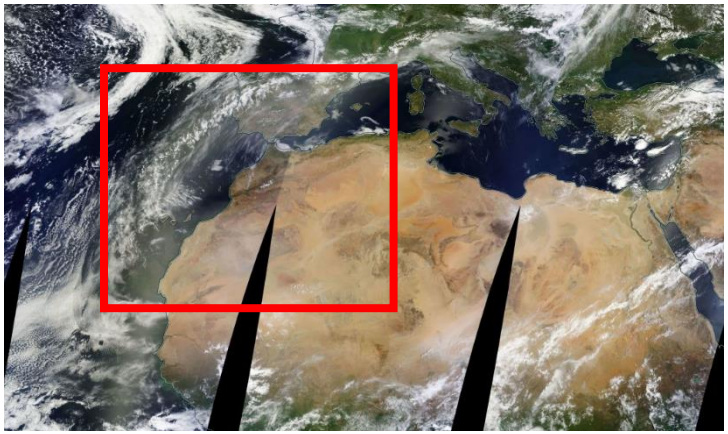


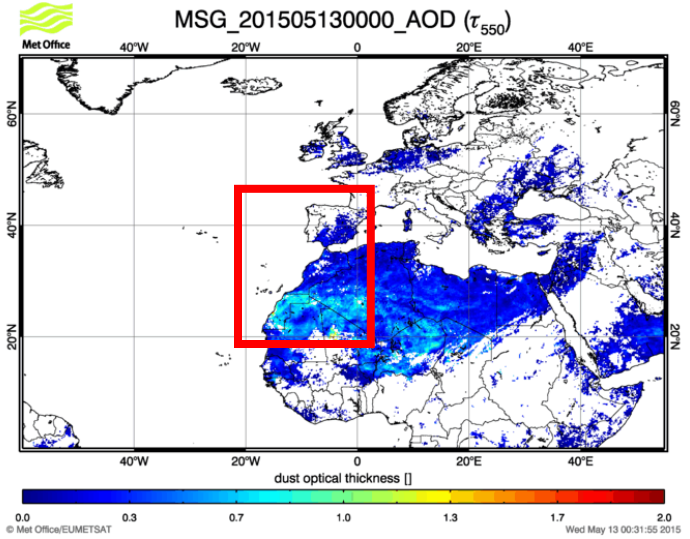
http://dust.aemet.es/

BDFC: Dust event Europe May 2015



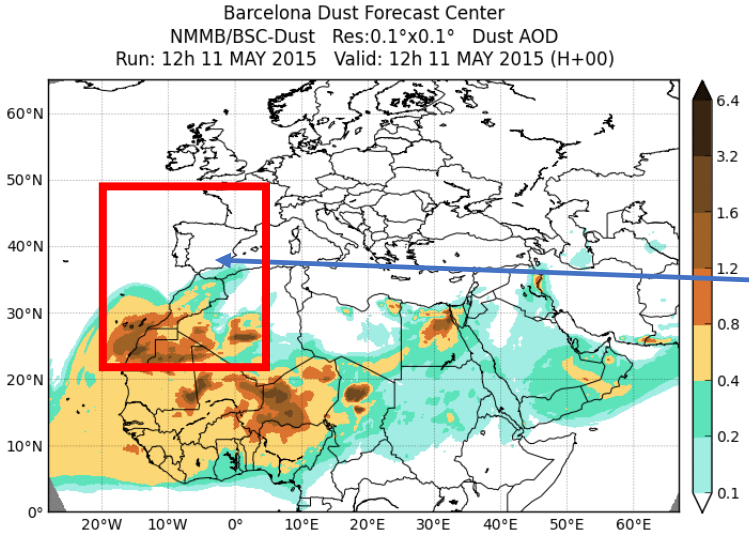


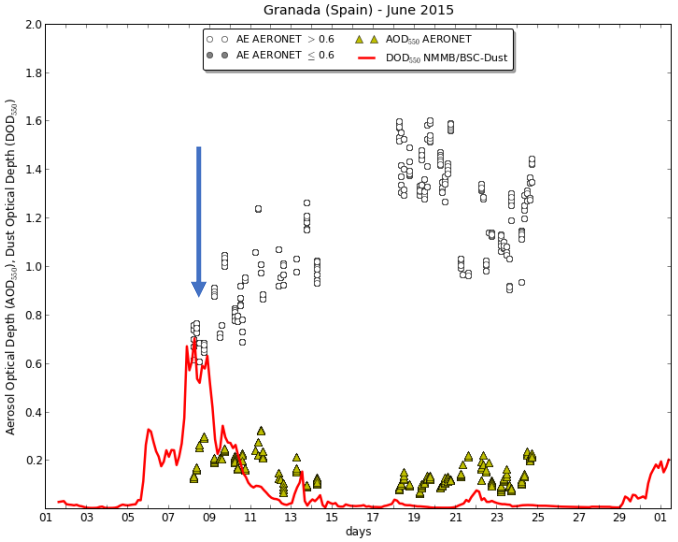


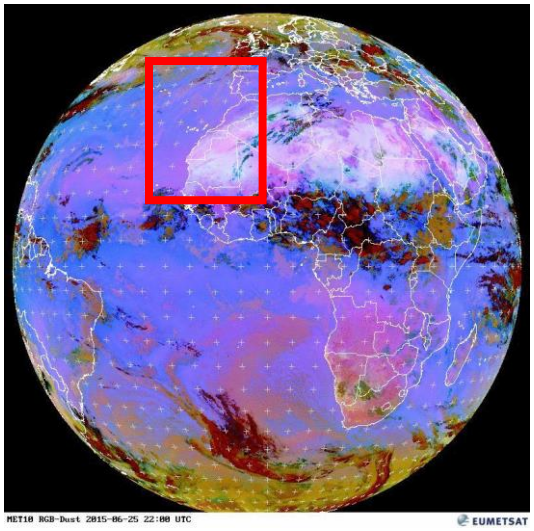


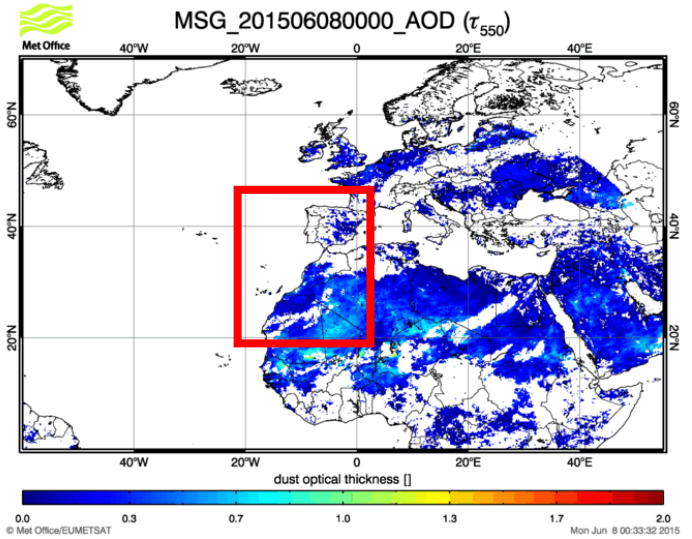
http://dust.aemet.es/

BDFC: Dust event Europe June 2015



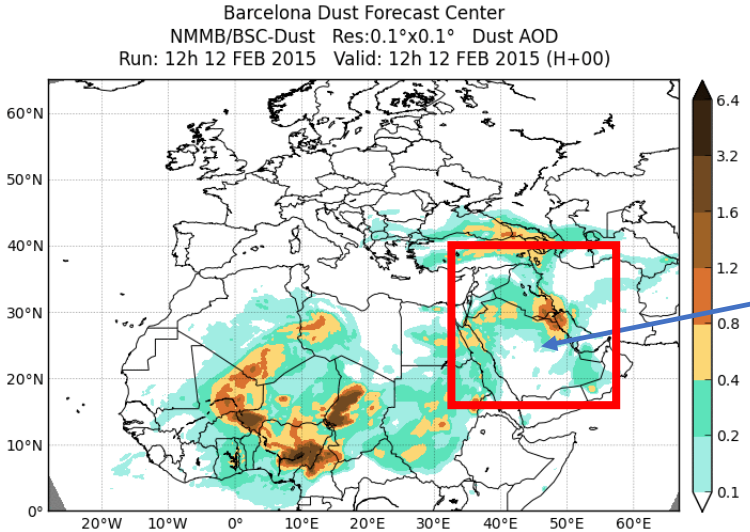


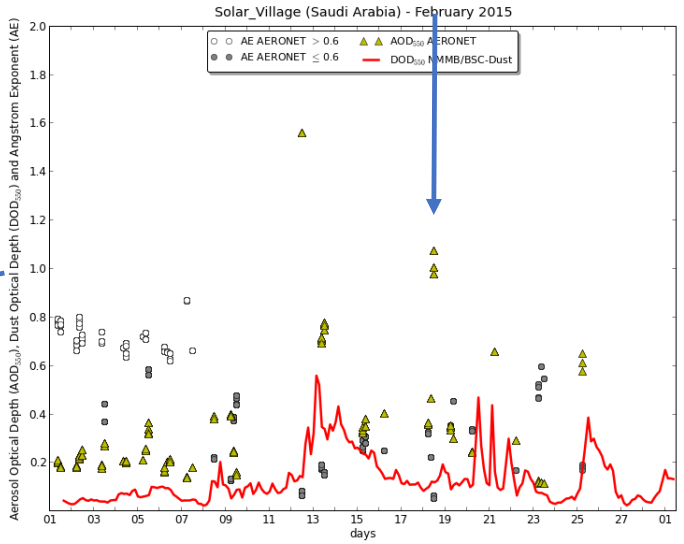


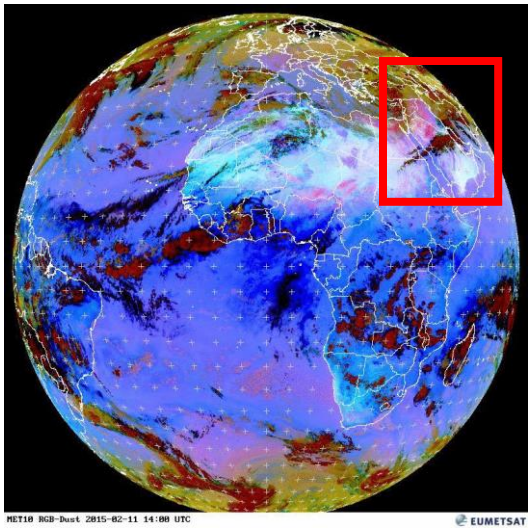


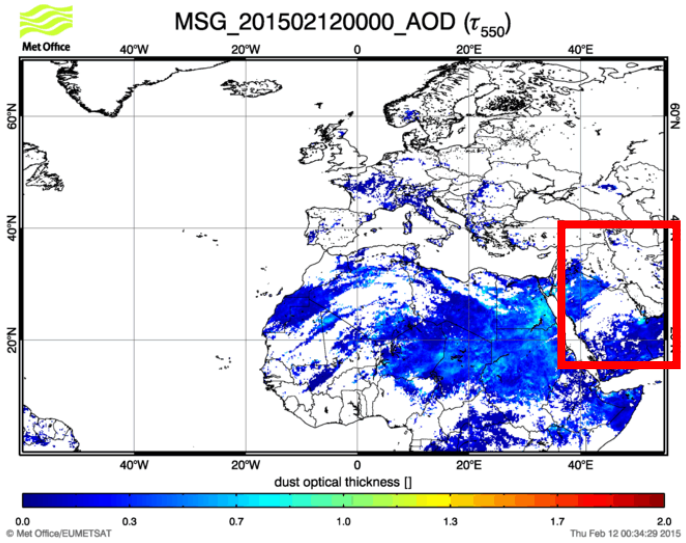
http://dust.aemet.es/

BDFC: Dust event Middle East Feb 2015



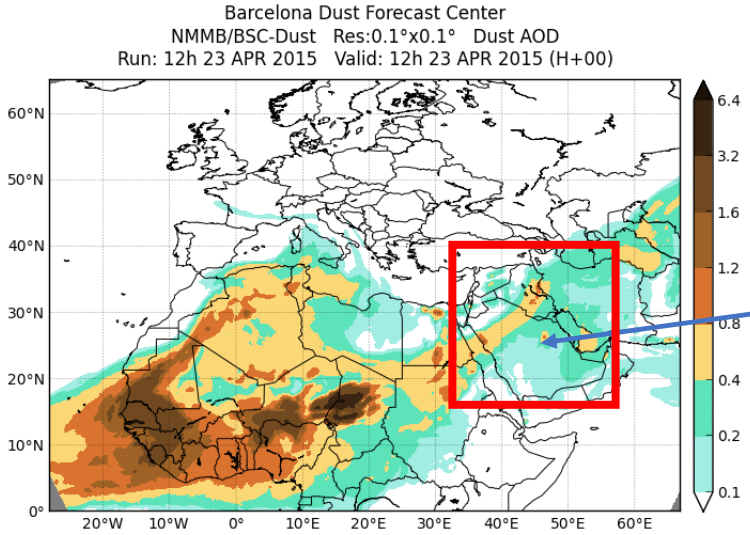


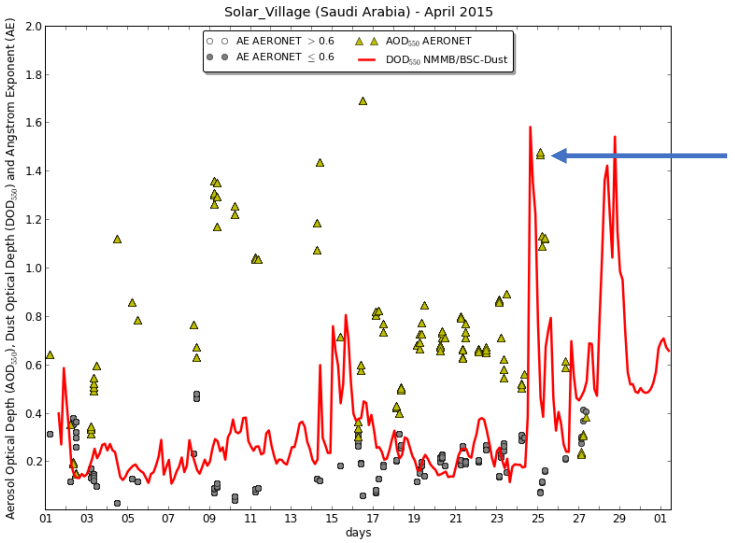


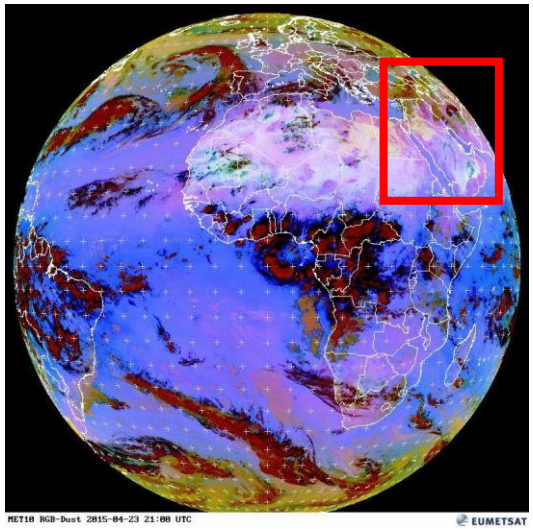


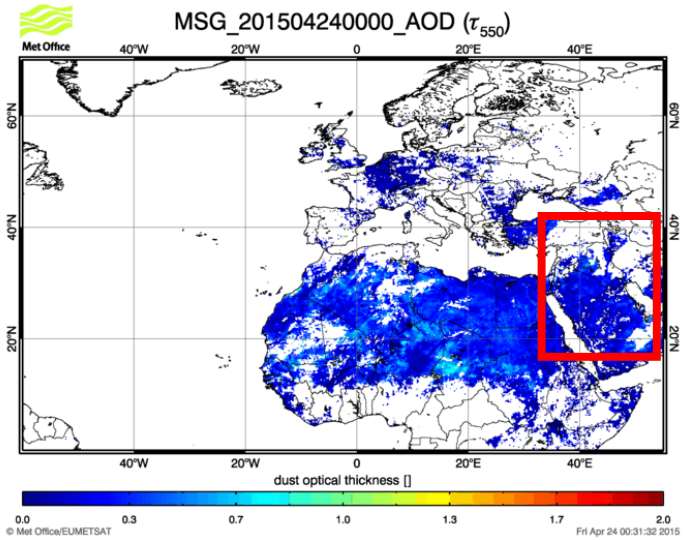
http://dust.aemet.es/

BDFC: Dust event Middle East Apr 2015



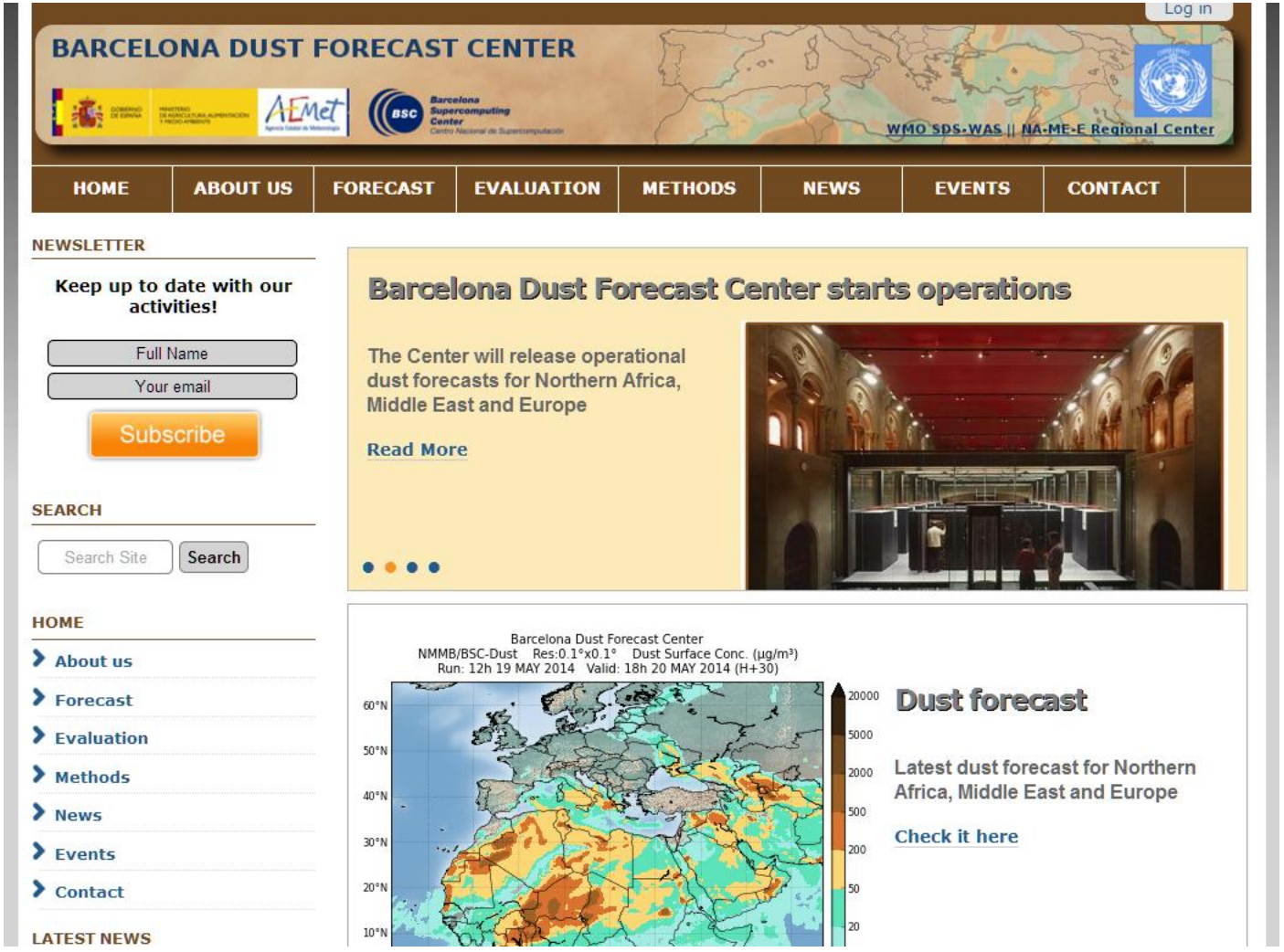






http://dust.aemet.es/

Barcelona Dust Forecasting Center



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EXCELENCIA SEVERO OCHOA

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